A STUDY OF THE FACTORS INFLUENCING THE DEVELOPMENT

AND THE YIELD OF THE POTATO

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A Thesis

Presented to the University of Edinburgh

for the

DEGREE OF DOCTOR OF PHILOSOPHY

January, 1948.

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INTRODUCTION

It can scarcely be doubted that of all the factors, those concerned with manuring have received the greatest attention in the field of experimentation in the case of the potato crop in the British Isles. Russel and Garner (1941) summarising the results of a large number of comprehensive experiments conducted at Rothamsted and associated centres, concluded that no other crop responds so well to all the three major nutrients, N, P_2O_5 and K_2O, as the potato. The three nutrients are interdependent so that in the absence of potash, $N+P_2O_5$ are sometimes worse than the control and develop characteristic potassium deficiency symptoms. The response to potash is, however, most variable, to phosphate less variable, and to nitrogen general, the last mentioned being much less affected by soil type, soil conditions (except on the fens) the presence or the absence of farmyard manure, or the basal yield. The effect of N is observed in the number and the size of the tubers; of phosphates more in an increase in number than in size and of potash mainly in an increase in 'ware'. The effect of N falls off slowly at higher dressings; of P_2O_5 more steeply and of K_2O most rapidly. Potash is indifferent to the physical properties of the soil but phosphates act best on heavy soils.

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The effect of manures on the size of the potatoes has also been separately reported (Garner, 1937).

Crowther and Yates (1941) utilized the available information from all the experiments conducted since 1900 in Great Britain, Ireland and parts of Europe to evaluate the specific requirements of different crops with respect to major nutrients and worked out optimal dressings in the presence and the absence of dung. They brought out the priority of potatoes for potash and the need for the reduction of the dressings of potash and phosphates in the presence of dung. It is possible, however, that their general recommendation may have to be modified, if the interactions of manuring with changes in some cultural practices suggested by the present investigation are borne out by further work.

Cowie (1943) examined the results of 186 experiments in Britain with reference to three forms of the potash fertilizer and found that the muriate of potash and kainit fell short of potassium sulphate in proportion to the chlorine content. The muriate and the sulphate of potash did not, however, differ significantly in yield. The effect of chlorine was demonstrable on the dry matter content of the tubers though the effect on the cooking quality was not consistent.

The poor performance of the potassic fertilizers containing 'chlorine' could be understood in terms of the field observations of Maskell (1927) on starch production./

He found that the rate of production and the translocation of starch were influenced by potassium sulphate but not by potassium chloride or potash manure salt. His observations, however, related to the later stages of plant development and were repeated by James (1930) who confirmed the ineffectiveness of the muriate and the potash manure salt on starch formation against the large effect of potassium sulphate, but translocation could not be definitely shown to be affected. James also made extensive physiological observations and found that potassium sulphate and low grade fertilizer reduced the number of leaves but muriate did not exercise this effect. The two chloride containing manures increased the size of the individual leaves and correspondingly the water content. Potassium sulphate neither affected the size of the leaves nor the water content. The distribution of the potassium in the plant organs was related to the water distribution (James, 1931; James and Penston,1933). This relationship, however, is not a proof of the role of potassium in the absorption of water or vice versa, for 'the type of plant produced and the physiological response observed depend quite as much on the other ions available to the plant as on the absolute level of the potassium itself' (Richards and Shih, 1940).

Watson (1936) attempted to resolve the rather paradoxical/

paradoxical position of marked response to the muriate of potash over no manuring, with no corresponding differences in starch, by studying diurnal changes of the carbohydrate fractions and dry matter at different levels of the muriate of potash. The absence of effect on starch production was confirmed, reducing sugars were unaffected, while the sucrose was depressed at noon. The interaction of the diurnal variation with the muriate of potash was rather complex.

Although, normally, the general requirements of the potato are nitrogen, phosphorus and potash under field conditions, there are cases on record where applications of calcium have proved imperative (Davies et al, 1944). This holds true where the soil is highly acidic and calcium is unduly depleted. This is understandable in terms of the proved importance of calcium for the potatoes, from the water culture experiments under controlled conditions (Gregory, 1928).

Despite the excellent work already done on the nutritional aspect of the potato, there is a lack of data on the modifying influence of the cultural factors such as planting time, spacing and seed size, on the fertilizer response. Moreover, there is little information on the interrelation of the cultural factors alone. Apart from this, some of them have not been subject to precise experimentation, even in isolation from one another.

The/

The effect of seed size on the resulting crop has, however, been the subject of many investigations (Salaman, 1921, 1922, 1923; Wallace and Thompson, 1933 Brandreth, 1935; Brandreth and Byran, 1937). Some of these trials adopted old layouts, were unreplicated or inadequately replicated and it seems the borders were not provided in most, if not all cases. Still the experiments yielded useful information. As a result of these trials, it has been generalized that the best size of the seed is equal to the size of a hen's egg (2 oz.). From a practical view point, however, the problem of seed size has to be approached in a different way. The commercial seed grade 1¼" x 2¼" varies all the way between 0.7 oz. and over 5 oz. per tuber. With such large variations it is natural to ask whether economy in seed could not be effected in the light of a possible relationship of seed size with the other factors. Bates (1935) reported the result of a two-factor seed size and spacing experiment which was repeated over two further seasons (Findlay and Sykes, 1938). The importance of the two factors on yield and size of the crop was established but the interaction was not significant. The range of seed size covered by these investigations was, however, too narrow (1 - 2.5 oz. per tuber) for the present day seed-grade commercial specifications fixed by the marketing board and the minimum spacing covered was 12 inches between sets.

Apart/

Apart from the aforesaid experiments the effect of spacing has not seemingly been investigated, alone or in relation to other factors. There is also a dearth of authentic published work on the 'planting time' factor. Such indirect evidence as is reported by Gregory (1944) points to the importance of this factor and therefore the need for its study in experiments specially laid out for the purpose.

Mention must be made here of the numerous agronomic trials conducted by the Department of Agriculture at Craibstone. The main findings have been detailed by Whitehead, McIntosh and Findlay (1945). It is, however, regrettable that these trials seem to suffer from lack of replication and rendomisation of treatments. The latter is a more serious defect as no valid estimate of error can be obtained even by regarding repetitions over years as replicates. These trials have, therefore, to be regarded as observations rather than accurate, critical, quantitative tests.

The foregoing considerations suggested a study of the diverse factors by laying out multi-factor comprehensive experiments on modern lines (Fisher, 1935; Yates, 1937) not only to evaluate their main effects but also their differential responses with changes in the level of the other factor or factors. In the first year, attention was confined to the study of cultural factors only, under a uniform system of manuring. Replicated observation plots were, however, provided/

provided under unmanured conditions and these suggested the usefulness of the simultaneous study of the nutritional and the cultural factors in a single large-scale experiment in the succeeding year.

It cannot be over-emphasised that interest in factors such as planting time, seed size is by no means restricted. These factors have far-reaching physiological significance. Seed size represents the initial capital with which the bud sprout starts off, and as growth is supposed to be exponential a small initial advantage in the form of reserve capital may have an enduring effect on the future plant performance. It is, therefore, of interest to find out how the food resources are mobilized, for the use of the daughter plants, from the mother tubers and how the plants react to the differences in their feeding from the mother tubers in the initial stages. Such a study furnishes an idea of the role of the mother tuber in the potato and an insight into the growth behavior of the plant.

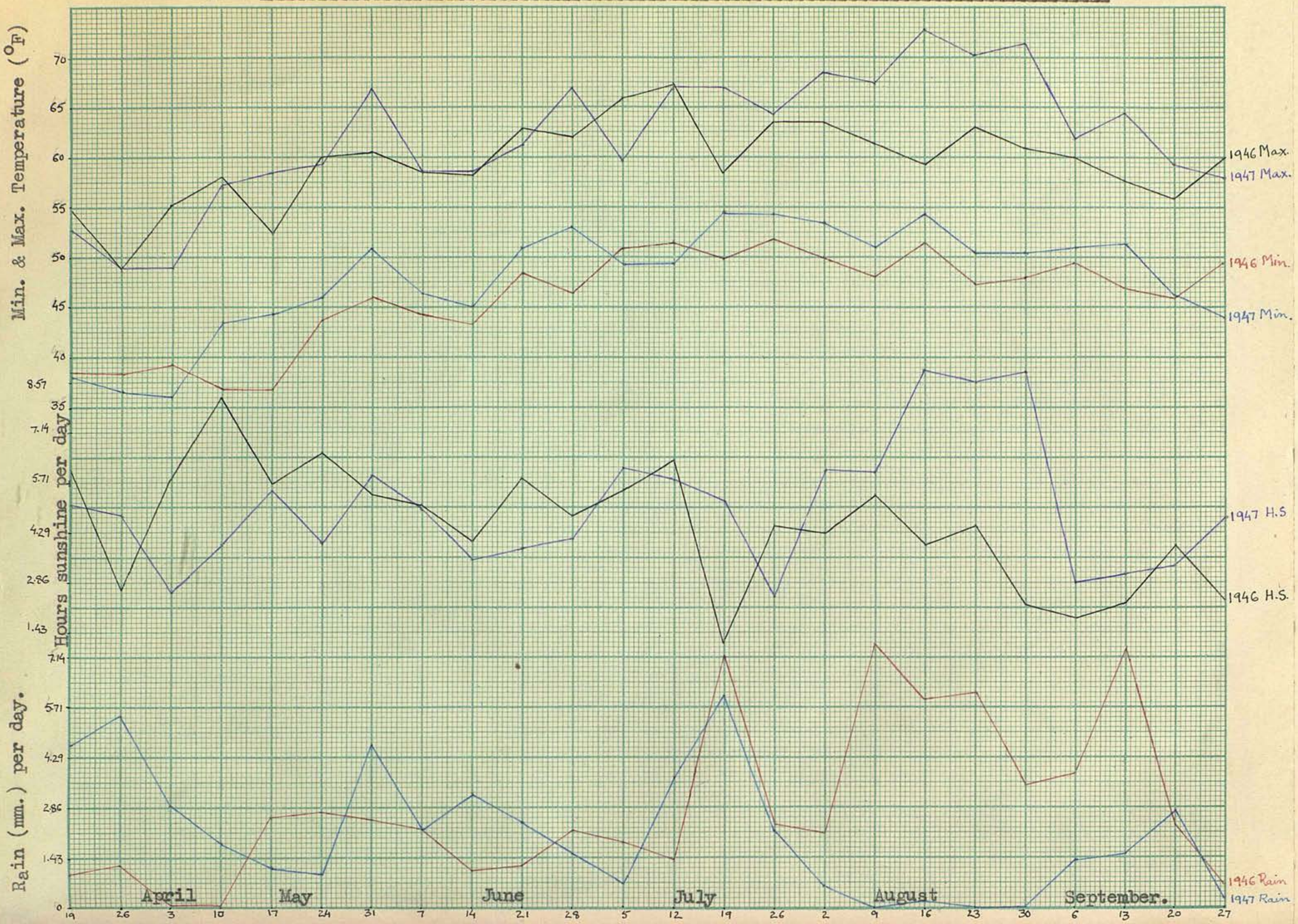
Planting time as a factor also furnishes interesting problems of scientific value. When a crop is planted late by a given interval, it is exposed to a different set of climatic conditions during its growth and a study of the plant reaction at the different phases of plant growth offers attractive opportunities for the assessment of the ecological and edaphic requirements/

requirements of the plant, not only from the point of view of economic returns but also total growth and the inception of different phases of plant growth. A useful application of this factor in ameliorating the bad opening of the bolls of American cottons in the Punjab, may be cited as an instance (Dastur and Singh, 1942).

Similarly, the specific roles played by the different nutrients can be studied in the field by employing the methods of growth-analysis developed by Briggs, Kidd and West (1920) and Gregory (1926).

Clearly, therefore it was necessary to supplement these studies by the collection of developmental data to trace the events leading up to the final yield. The experiments were conducted over two seasons to study the controlling influence of the weather factors on the performance of different treatments.

Fig. 1 MAXIMUM AND MINIMUM TEMPERATURES, HOURS OF SUNSHINE AND RAINFALL (1946 and 1947)



SEASONAL FEATURES (1946 and 1947)

The climate conditions in the two seasons over which the experiments extended varied widely both in the preplanting period and during the crop cycle. The two seasons represented extreme conditions in almost every way.

1946 was a year of milder winter and bright early spring so that work could be taken well up in time. 1947 will long be remembered for its long dreary winter, heavy snow fall and late wet spring, which postponed new year's agricultural work by at least one month.

The important meteorological data from the third week of April to the end of September relevant to the potato crop, is given in Fig. 1, for the two years. Maximum (^{O}F), minimum, (^{O}F), hours of sunshine, rainfall (mm.) per day calculated from weekly totals are plotted against the central dates of the successive weeks.

The minimum temperature had a well-defined trend rising steadily to a high value towards the middle of July, after which it steadied down and then fell off very very slowly. The trend was virtually the same in the two seasons, and the deviations from the trend within seasons were small in magnitude. The variations between the two seasons in the minimum temperatures were well-defined, regular and extended over long periods/

periods, although they were not high in magnitude. The general trend of the maximum (day) temperatures with time was similar to that of the minimum (night) temperatures but the day temperatures showed greater fluctuations both between and within the two seasons.

The night temperatures were consistently higher in 1946 up to the first week of May. Thereafter, throughout the rest of the potato season, with the exception of the first fortnight in July, they were lower than those obtaining in 1947. As the utilization of foods proceeds to a considerable extent at night, the conditions for growth were ideal in 1947, so far as this factor was concerned.

The day temperatures were higher in 1946 than in 1947 up to the middle of May and lower for over two months from the middle of July, agreeing well with similar trends for the night temperatures. The month of August was particularly hot in 1947 and the weekly mean maximum temperature went as high as 73° F. July was the hottest month in 1946 and the maximum temperature did not rise higher than 67° F. The days were warmer in 1947 during May but the two seasons were alike during June.

1946 was characterised by bright, sunny and dry weather up to the middle of May when the long spell of dryness gave place to welcome showers. 1947 was wet and dull with occasional breaks of fine weather as far as the early part of May i.e. prior to plantings/

plantings. The early and the midseason had, in general, less of radiation and more of showery weather in 1947 as compared with 1946. Really contrasting features developed in the two seasons early from the month of August. 1946 was a year of abundant continual rainfall during the phase of active tuberization, but lacked in sunshine. On the other hand, 1947 was characterised by long hours of bright sunshine, and prolonged drought which upset the water relations of the plants, more so under heavy soil and heavier dressings of nitrogen. A mild improvement occurred in the month of September in 1947 but it was rather late and insufficient to make good the loss sustained from the preceding drought.

Thus the season in 1947 was warmer, brighter and drier, in the tuberization phase of the crop, as compared with 1946.

Both the seasons were free of late morning frosts which sometimes menace early sprouting in the potato. The attack of late blight (Phytophthora infestans) was kept in abeyance in 1946 by low temperatures in August, despite the wet summer, and in 1947 by bright and dry weather. In the former case, blight came on early in September and spread rapidly.

It appears the dry, warm and still summer in 1947 must have favoured the multiplication of aphids and virus attack may spread to an alarming extent in the following year.

INVESTIGATION.

1946

DESCRIPTION OF THE EXPERIMENTS (1946)

A comprehensive set of experiments was conducted in the Anchordales field at the Boghall Experimental Farm, 5½ miles from Edinburgh (Lat. 55°. 55'N, long. 3°.10'W) at an altitude of 639 ft.

An area of about 2½ acres, measuring 300 ft. x 360 ft. was selected for the experiments. The soil according to an earlier survey was originally boulder clay based on a high percentage of basic igneous rocks. It was chocolate in appearance. The surface soil was predominantly gravelly, sandy loam with free working tilth having a moderately compact but penetrable subsoil. The sandy character inclined to increase from the West to the East. This was associated with a regular downward slope in the same direction, as far as the middle of the area selected, followed by a more or less level ground. The soil pH ranged between 6.4 and 7.1. The field was of medium fertility. The previous crop was oats. The field was ploughed and dunged at 15 tons per acre in the winter.

The area was harrowed in the first week of April and ridges were drawn at 27" with a 3-row potato ridger driven by tractor. It was then laid out into plots to accommodate one main experiment and subsidiary small-scale experiments for taking some special/

Special observations.

The Four-factor Experiment

Treatments and Layout: The main experiment comprised a study of all combinations of:

Factors	Planting Date	Inter-set Spacing	Seed Size	Time of Lifting
Symbol	D	Sp.	Ss.	T
Levels	d_1=10.4.46	8"	s $1\frac{1}{4}$" x $1\frac{1}{2}$"	t_1 haulm killed on 8-10.9.46.
	d_2=30.4.46	16"	m $1\frac{3}{4}$" x $1\frac{7}{8}$"	t_2 allowed to mature naturally
	d_3=20.5.46	24"	l $2\frac{1}{8}$" x $2\frac{1}{4}$"	

with fourfold replication. There were thus 54 treatment combinations and 216 sub-plots. The design adopted for this experiment was split-plot with confounding (Fig. 2). The experimental area was divided up into four main-blocks of $121\frac{1}{2}$' x 150', to lie in two rows. Three unplanted headlands 20' wide each were provided for the movement of implements from plot to plot. The nine combinations of planting time and spacing lay in a random order in long narrow main plots $13\frac{1}{2}$' x 150', running the entire block length, in each of the four main blocks. Each main plot was split across into three plots, $13\frac{1}{2}$' x 50' for the allocation of the three seed sizes at random with the restriction that the triple-factor interaction was confounded with the transverse sub-blocks thus formed within the main blocks. There were 8 degrees/

degrees of freedom, forming four orthogonal pairs, corresponding to the second-order interactions; and in different blocks, different pairs were confounded attaining a perfect balance in the four replicates and thus retaining 75% of the relative information on the triple-factor interaction as well.

In September, the 12 sub-blocks (4 x 3) were split transversely for the two times of lifting. The haulms of a half strip of each sub-block were killed with Sodium chlorate spray at 25 lb. solid substance per acre, on 8 - 10 September. The unsprayed half of each transverse block was allowed to mature naturally. The final division increased the number of plots to 216. The ultimate size of the sub-plot after rejection of border rows and edges was 9 ft. x 22ft. The gross sub-plot measured 13½' x 25'.

The layout of the experiment was carefully planned, giving due consideration to the purpose of the experiment, the direction of the slope and its possible relation to the fertility differences, and the cultural requirements. The salient features of the layout are: (1) Large, long and narrow mainplots for the planting dates facilitated agricultural operations and reduced the area under headlands as much as possible. (2) Six rows per plot at 27" constant drill width permitted the use of two-row as well as three-row implements without any waste of labour/

Fig. 2.

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Layout plan of the 3 x 2 Factorial Experiment on potatoes at the Boghall Experimental Farm. 1946.

N

Block No:-	X_2	X_3	X_1	Z_2	Z_1	Z_3	
	t_2 t_1	t_2 t_1	t_1 t_2	t_1 t_2	t_1 t_2	t_1 t_2	
d_1 8"	m	l	s	s	l	m	d_1 16"
d_2 8"	s	m	l	l	m	s	d_3 8"
d_2 24"	l	s	m	m	s	l	d_1 8"
d_3 24"	m	l	s	l	m	s	d_2 16"
d_1 16"	l	s	m	s	l	m	d_2 8"
d_3 8"	l	s	m	m	s	l	d_3 16"
d_1 24"	s	m	l	m	s	l	d_2 24"
d_3 16"	s	m	l	l	m	s	d_1 24"
d_2 16"	m	l	s	s	l	m	d_3 24"
d_1 24"	s	l	m	l	s	m	d_2 24"
d_1 16"	l	m	s	m	l	s	d_3 16"
d_1 8"	m	s	l	s	m	l	d_2 16"
d_2 24"	m	s	l	s	m	l	d_1 8"
d_2 8"	l	m	s	l	s	m	d_1 16"
d_3 24"	l	m	s	s	m	l	d_3 24"
d_2 16"	s	l	m	m	l	s	d_2 8"
d_3 16"	m	s	l	m	l	s	d_1 24"
d_3 8"	s	l	m $13\frac{1}{2}$"	l	s	m	d_3 8"
	t_1 t_2	t_1 t_2	t_1 t_2	t_2 t_1	t_2 t_1	t_2 t_1	
Block No:	Y_3	Y_1	Y_2	W_1	W_3	W_2	

<-----------150 ft----------->

d_1, d_2, d_3 denote successive planting dates } main plot treatments
8", 16", 24" denote spacings in inches. }

s, m, l, denote small medium and large seed: sub plot treatment

t_1 t_2 denote early and late lifting: array strip treatment.

The direction of rows was East-West.

labour, since six is a multiple of two as well as three. (3) Square blocks and long and narrow main-plots were provided as potential devices to keep down experimental error. (4) The seed-size treatment lay end on, by transverse division of the main-plots. Any risk of fertility gradient within the blocks in the same direction, as suggested by the slope, was obviated through confounding. (5) The effect of lifting time was studied in long narrow transverse strips so that its interactions with other treatments could be measured with greater precision.

<u>Seed</u>: The variety used was Gladstone certified stock seed obtained from the north of Scotland. The use of healthy stock seed was necessary in all fairness to the small seed. The seed scheduled 1¼" x 2¼" was riddled to strip out the desired seed sizes. For greater uniformity within each of the three seed grades required, riddles rising by ⅛" had to be used. About 7½ tons of seed was dressed to get the required quantities of the three different grades used in this experiment as well as the observation plots. The seed sizes designated as small (s), medium (m) and large (l) weighed, on the average, 1.1, 2.4, 4.3 g. per tuber respectively.

The seed was placed in sprouting trays, as it was being dressed and used in the three plantings on due dates. There were slight signs of chitting when the second planting was done but sprouting had not ad-vanced/

advanced very far. At the time of the third planting the sprouts in the trays were well developed but as they were kept in a well-lighted shed, sprouts were strong and sturdy, about 1" in large seed, ½" - ¾" in the medium seed and less than ½" in the small seed.

<u>Spacing</u>: To ensure accuracy of spacing according to the plan, six ropes 50' long, two for each of the three spacings were marked at the specific distances, 8", 16" and 24", by tieing coloured twine.

<u>Manuring</u>: In addition to the application of dung in the winter, a basal dressing of the compound potato fertilizer (composition: N 6%, P_2O_5 8% Sol., 1% Insol.) K_2O 12%) was given before each planting at 10 cwt. per acre.

<u>Cultural Operations</u>: The cultural operations followed closely the standard agricultural practices prevalent at the Boghall Experimental Farm. The area was kept spotlessly clean by inter-row cultivations and hand-hoeing. It must, however, be stated that ridging up as the last cultural operation was done all over on 9 - 11.7.46. Ideally it would have been better to ridge up plots of different treatments at similar stages of morphological development rather than the same date. Lifting was done on 19 - 22.10.46 with the mechanical spinner, combined with hand lifting, to/

to keep the produce of each sub-plot separate. The produce of each experimental bed was bagged separately conveyed to the store to await dressing and weighment.

<u>Data Collected</u>: The following records were maintained from the main experiment.

(1) The counts of the emergence of sprouts above-ground at 2-day interval from 2.6.46 were taken on plots under 16" spacing.

(2) The height of plants was recorded on 8 plants per plot thrice in the season.

(3) The nodal counts of the plants under height observation were taken finally from one replicate.

(4) Total yield and the yield of the commercial grades, viz., ware (over $2\frac{1}{4}$" meshed riddle) seed ($2\frac{1}{4}$" x $1\frac{1}{4}$") and chats (through $1\frac{1}{4}$" riddle), were recorded for each sub-plot separately.

Sampling Procedure and Analytical Methods:

Two series of plots were provided for sampling:

(1) Studies in the Early Stages: The effects of seed size on the number of sprouts, early development, depletion of food material from the mother tubers, and the concentration of sugars in the mother tubers, were determined from a simple randomised block experiment with three seed sizes and six replicates. The average seed sizes were 30, 70, and 130 g. per tuber respectively. Each plot consisted of a single row 48' long, planted at a uniform spacing of 16" between sets on the 11th April. The area under this experiment was not manured.

The seed for this experiment was specially prepared for uniformity. A preliminary selection by eye was first made from the general lots designated as small, medium and large in the main experiment. Subgrades were then made. Each tuber was then weighed individually to finalise selection of individual tubers conforming to the mean of the respective subgrades with an accuracy of 0.5, 1, 2 g. per tuber in case of the small, medium and the large seed respectively. With the sample size of 5 tubers per plot, this amounts to an error of less than 1% in the fresh weight. A mean of six replicates will be expected to be still less variable. It may, however,/

however, be stated here that extreme standardisation of seed does not necessarily carry very far in the accuracy of sampling, for other sources, such as differences in water content, time of sprouting, number of sprouts, introduce errors in sampling to a greater extent.

Samples were retained before the planting, for the determination of dry matter and sugars on 15th April. Samples were taken at 4 stages later as below:

on - 28-30 May (at emergence of sprouts) - All Replicates
11-13 June (at the leaf expansion stage) "
29 June (onset of tuberization) "
16 July (onset of flowering) In duplicate only.

To reduce work to a manageable unit two replicates per day were sampled at each stage, extending over three days.

<u>Dry Matter Determinations</u>: The vegetative parts of the samples were dried in a large electric oven, (Incorporating a fan) at 95°C - 100°C. The roots were thoroughly washed and excess moisture wiped off, before they were transferred to the oven.

The mother tubers were thoroughly washed, dried with a cheese cloth and weighed to record the fresh weight. They were then chopped up and passed through a hand-driven mincer, 100 g. of pulp was taken for each dry matter determination and dried in the oven for 48 hrs. at 95°C. 20 g. pulp were taken for sugar estimation.

<u>Sugar</u>/

<u>Sugar Estimations.</u> (Method) 20 gm. of pulp is boiled with neutral alcohol (50 c.c.) for 5 minutes and the extract is filtered into a 100 c.c. flask and stored to await analysis.

The alcohol is evaporated, the residue taken up with water and the volume made up to 150 c.c. approximately. Proteins are then precipitated with 5 c.c. saturated neutral lead acetate. After 15 minutes the excess lead is precipitated by adding 20 ml. Sodium oxalate (saturated) solution. After one hour the solution is filtered into a 200 c.c. volumetric flask and the volume made up to mark.

Sugars are estimated by the Lane Eynon method (modified). 50 c.c. of the unknown solution (containing less than ·1 g. of sugar) are added to the 20 c.c. Fehling's solution, (10 c.c. A + 10 c.c. B.) brought to boiling and titrated with standard inverted sugar till the copper is completely reduced. The reducing sugars are calculated from the amount of standard sugar necessary to complete the reduction.

For the estimation of total sugars 50 c.c. of the unknown solution are inverted with 10 c.c. HCl (S.G. 1.1029) in a water bath at 70°C for 5 minutes. The solution is then cooled, neutralized with 40% NaoH and volume made up to 100 c.c. 50 c.c. are used for sugar estimation as above. The dilution is taken account of in calulation. Non-reducing sugars come by difference. (Total sugars - reducing sugar).

The appropriate factors are used in the expression of results as glucose and sucrose.

(2) Growth studies in the later stages:

The effects of spacing and seed size on growth, the number and the size of tubers, and the distribution of tubers in space were investigated under similar conditions of manuring and cultural operations as the main experiment. For this purpose, in the same field, a split-plot experiment with spacing as the main plot treatment and seed size as the sub-plot variable was laid out with three replications, (Fig.3). The planting was done on 11 April. Each subplot contained 100 plants and 4-5 plants per subplot were sampled thrice in the season.

Borders rows were provided between the mainplot treatments but not between seed size comparisons.

Fig.3. Layout plan of the seed size and spacing plots for observation.

Block I	Block II	Block III
16" (s, l, m)	24" (s, m, l)	8" (l, m, s)
24" (l, s, m)	8" (m, l, s)	16" (l, s, m)
8" (m, l, s)	16" (s, m, l)	24" (s, l, m)

s, m and l represent small, medium and large seed respectively.

8", 16" and 24" represent the interset spacing.

Statistical Analysis and the Method of the Presentation of Data.

The data were subjected to the 'analysis of variance' appropriate to the designs. For the yield data of the main experiment there were four separate estimates of error, applicable to: (a) the effects of planting dates, spacing and their interaction; (b) the effect of seed size and its interactions with the main-plot comparisons; (c) the generalized effect of lifting time; and (d) The interactions of time of lifting with all the others. It was clearly necessary to account for, in the analysis of the data, all the restrictions imposed in the form of split-plot arrangement and confounding.

The split-plot experiment (spacing x seed size) was comparatively simple. There were two estimates of error: (a) relating to the main effect of spacing (b) appropriate to the seed size main effect and its interaction with spacing.

To economize space, the methods of statistical analysis have not been described in detail. Reference may be made to Yates (1937) for guidance on the subject. In the presentation of results, commonly adopted notation is followed throughout. The main effects and interactions are denoted by capital letters (D, Sp., Ss., T.) and the levels or the treatments by small letters e.g. $d_1, d_2, \ldots s$, m, l etc. Where the main effects and the interactions of the three-level factors are split into the linear and the/

the quadratic components they are denoted by a single dash and double dashes respectively. (The dashes used to denote inches in case of spacing need cause no confusion with the use of dashes in the above sense).

The progressive data on height and on the depletion of food material from the mother tuber are graphically represented. The other information is recorded in the form of two-way tables, on the basis of the statistical analysis, with the appropriate standard errors, in most cases. The differences greater than $S.E_{(mean)} \times \sqrt{2} \times t$ (Fisher and Yates, 1943) should be judged as significant.

As is customary, results significant at the 5% level of significance are marked with one asterisk (x) and those at 1% level, with two asterisks (x x), in the tables of results.

EXPERIMENTAL RESULTS.

Treatment Effects on Plant Development.

The Emergence of sprouts from the ground.

The sprouts appearing above ground at the successive dates of observation were expressed as a percentage of the number which finally emerged in case of each treatment. Table I shows the progress of sprouting under different conditions.

Seed size and sprouting. Obviously, the time of emergence of sprouts from the ground was related to seed size. Sprouts from small seed came through the ground later than those from the medium seed, which in turn were behind the sprouts from the large seed in emergence. This behaviour was well-marked in all the plantings.

To have a quantitative idea of the extent of delay with decrease in seed size, the best criterion is to calculate the mean date of emergence which can be defined as the date on which 50% of the stand is completed. This is done for the third planting in Table II A which also includes the dates on which 25% and 75% of the 'hills' were full. On the average, the sprouts arising from small seed emerged six days later than those from the large seed and four days later than those from the medium seed.

The data relating to seed size effect on sprouting was subjected to statistical analysis. For this purpose a germination rate index (Bartlett, 1937) was worked out for each plot of the third planting.

The/

Table 1 . The influence of planting time and seed size on the percentage stand.

Planting	seed size	Dates. 2/6	6/6	8/6	10/6	12/6	14/6	16/6	18/6	20/6	22/6	24/6	26/6	28/6	2/7	4/7
d_1	s	41.8	68.3	84.7	89.1	-	95.7	97.7	-	-	100					
	m	59.4	75.1	87.5	90.6	-	95.3	97.3	-	-	100					
	l	68.1	84.3	91.6	93.9	-	97.4	98.5	-	-	100					
d_2	s		9.3	24.1	33.6	-	66.1	78.5	83.5	88.2	94.2	97.6	98.4	99	99.8	100
	m		26.5	56.1	64.2	-	87.8	94.5	95.9	96.8	98.8	99.4	99.7	99.8	99.8	100
	l		55.5	77.5	84.3	-	95.0	97.3	98.3	98.9	99.3	99.5	99.5	99.9	99.9	100
d_3	s			-	0.7	-	2.7	11.7	18.9	32.9	60.8	84.9	91.9	93.7	98.5	99.4
	m			0.1	2.1	-	22.7	45.5	58.7	72.4	86.3	93.6	96.7	98.1	99.4	99.7
	l			2.7	8.5	-	39.2	61.6	74.7	83.4	92.2	96.1	97.3	98.4	99.4	99.9

The rate index employs experimental readings at all stages and summarises them by a single value. The 'analysis of variance' reveals that the effect of seed size on sprouting was highly significant (Table II B).

<u>Planting time and the rate of emergence:</u> That a delay in the time of planting should cause a delay in the date of plant establishment is to be expected but it is the magnitude of delay in emergence, in relation to the delay in planting, which is important. This necessitates a consideration of the number of days taken by different plantings to appear above ground (Table III A). It is interesting to note that the later plantings took less time in coming through the ground. The second planting remained in the ground for about 11 days longer than the third, and the first one a fortnight more than the second. This tendency for earlier emergence relatively, with delay in planting reduced the gap between the successive plantings in the matter of their aerial existence. Thus the date of emergence of the three plantings followed more closely than the differences in their planting time would lead one to expect (Table III B). The gap between the first two plantings narrowed down to about 6½ days and that between the extreme plantings to about 16 days corresponding to differences of 20 days and 40 days respectively in the time of planting.

The process of the emergence of sprouts from the ground evidently proceeds in a number of stages:
(a)/

Table IIa. Mean date of emergence in June in relation to seed size.

Seed size	Percentage stand. 25%	50%	75%	mean
s	19.0	21.2	23.2	21.1
m	14.2	16.8	20.4	17.1
l	12.8	15.0	18.0	15.3

Table IIb. Analysis of Variance of 'Germination Index'

Due to	d.f.	mean square	F
Blocks	3	.00485	
Seed size	2	.04531	67.2 xx
Error	6	.000674	

Table III. The Relation of planting date to sprout emergence.

A. Number of days taken to establish 68% stand

B. Mean date in June when 68% of the stand was complete.

	A. d_1	d_2	d_3	B. d_1	d_2	d_3
s	57	45.3	33.5	6	14.3	22.5
m	55	41.7	30.5	4	10.7	19.5
l	53	38	28	2	7	17
mean	55	41.6	30.7	4	10.6	19.7

Table IV. The relation between seed size and the number of sprouts per tuber.

Seed size	Date of observation 28-30/5	11-13/6	mean	15-17/7
s	3.4	3.3	3.35	3.0
m	5.0	5.1	5.05	5.0
l	7.5	7.7	7.6	6.6
S.E.			$\pm$.221	$\pm$.208

(a) The buds swell up and begin to make a slow growth (b) The sprouts send out roots, if they are surrounded by a rooting medium (c) Water and mineral matter are absorbed by the roots, resulting in a rapid elongation of the internodes and the bringing of the young sprouts near the soil surface. The first stage can be initiated in the tubers in the sprouting boxes, by virtue of a high moisture content in the tubers (75-80%). This constitutes a compensation to the later plantings if the young sprouts are well supplied with light, during their storage, and further if these sprouts are not knocked off in handling at planting.

But the later plantings would always be at a disadvantage with regard to the second and the third stages. The sprouts cannot root unless they are in contact with a rooting medium. This disadvantage would reflect differences in the date of emergence of the different plantings, although the rising temperatures in spring are a certain compensation for the later plantings. The gap between the early and the late planting may be modified by the prevailing temperatures and the moisture conditions in the soil. The month of April and the early part of May were unusually dry and cold in 1946, inasmuch as the first two plantings differed only by a week in the date of emergence, while the difference was greater between the central and the third planting.

Seed size and the number of sprouts: The differences among the plots planted with different seed size were/

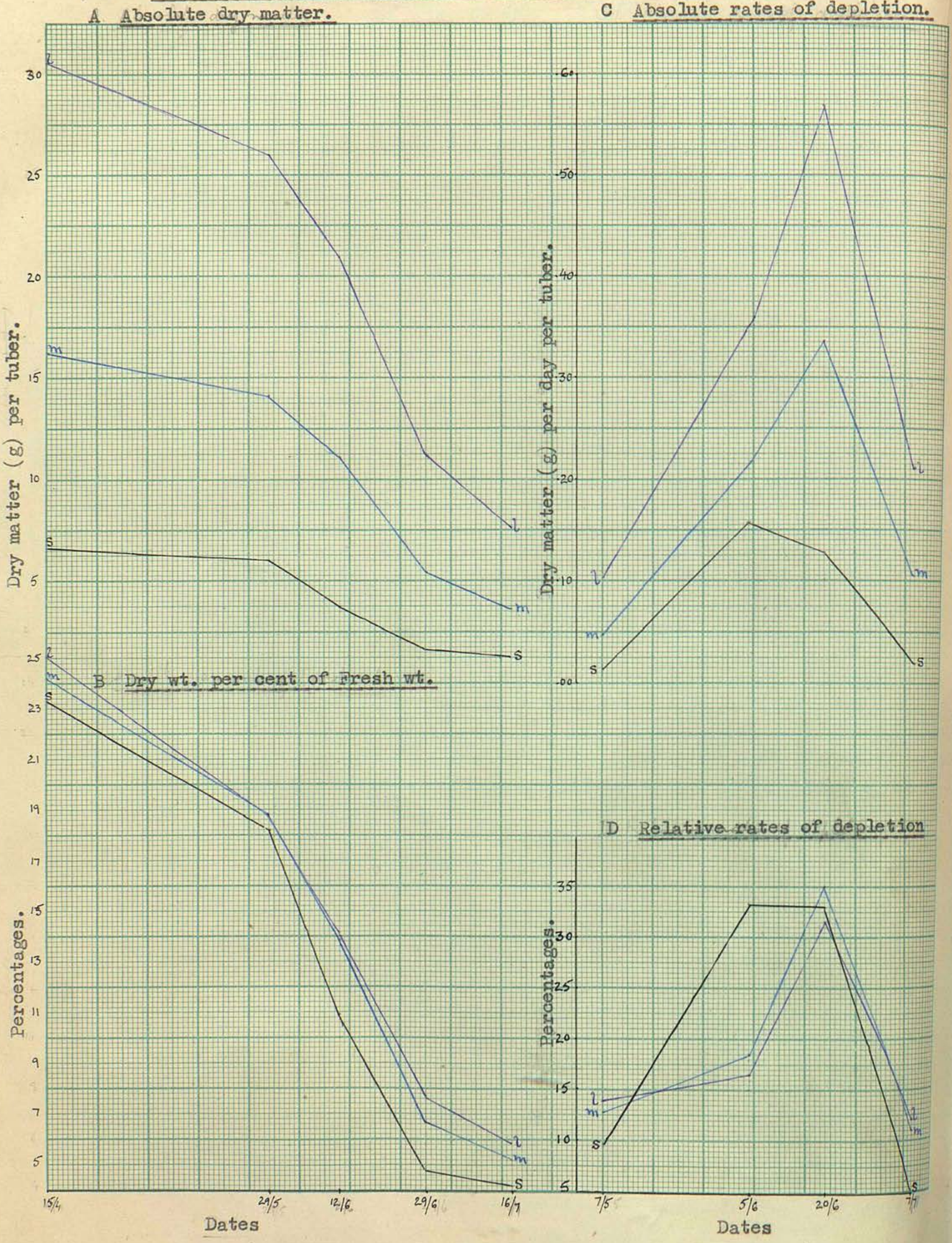
were even more conspicuous to the eye in the early stages than the differences in the number of days taken by them to sprout would suggest. The plants from large seed were more vigorous in appearance than those from the small seed, due partly to early emergence and partly to the greater crowding of sprouts per tuber (Table IV). The relation between seed size and the number of sprouts was direct, consistent and highly significant. Similar relationship was found by Bates (1935) with the variety King Edward. It is therefore of general occurrence in the potato.

Although the relation between seed size and the number of sprouts was direct, it was not proportionate to the weight of the seed i.e. doubling the seed size did not double the number of sprouts. The variation in the number of sprouts with seed size is a measure of 'apical dominance' in the potato. As 'apical dominance' seems to be associated with a hormonal mechanism, it is highly probable that the different seed sizes vary in the content of the growth-regulating substances. Direct evidence on this subject is however, lacking, although Appleman (1918) suggested the possibility of the limitation of special growth substances in the small seed.

<u>The rate of depletion of food material from the mother tuber</u>:

The absolute drymatter in the tubers of the three seed sizes was 6.6, 16.2, and 30.6 g. per tuber respectively, in the beginning. The dry matter fell off progressively as the time advanced on account of depletion to set up the/

Fig. 4 SEED SIZE EFFECT ON THE DRY MATTER CHANGES IN THE MOTHER TUBER (1946).



the sprouts and respiration losses. (Fig. 4 A). The fall in dry matter was steeper as the seed size enlarged.

The fresh weight, on the other hand, increased considerably after planting. The gain in the fresh weight was of the order of 10-15% over the weights of the tubers in the first week of April and occurred in all seed sizes. Thus the seed tubers were continually being replenished by water in place of the dry matter lost and the amount of ingoing water exceeded the dry matter removed or lost in respiration. Gain in fresh weight of the mother tuber may be a normal feature, for the tubers are continually losing moisture in the pit from harvest in Autumn till the planting time in spring. In the present case the seed was got from the North and was then graded for planting and lay in the boxes for some days before going into the ground. Thus at least a fortnight intervened between the removal of seed from the pit and planting time. The losses during the storage and the preplanting period are apparently made good after planting if the moisture supply of the soil is adequate.

As a result of the falling dry matter and the rising fresh weight, the dry matter percent fell off steeply at the successive stages of sampling up to the end of June when the percent dry matter was so low that further reduction was small and gradual. (Fig. 4 B) Throughout, the dry matter percentage was uniformly low in the small seed, while there was no difference between/

between the large and the medium seed.

<u>Absolute rate of depletion</u>: The absolute loss of dry matter per day for each interval is plotted against the mid point of each interval in Fig. 4 C. The depletion of food material from the mother tuber was progressively higher as the seed size increased throughout the period of study. The peak rate of depletion occurred in the large and the medium seed at the end of June, but in the small seed it occurred earlier.

A higher depletion rate in the larger seeds was to a large measure, accounted for by a corresponding increase in the number of sprouts per tuber. When the rates of depletion were calculated per sprout (Table V) the disparity between tubers with respect to loss in dry matter per sprout, scaled down considerably. Still the balance remained in favour of sprouts from the large seed, which were better nourished individually than the sprouts from the small or the medium seed. This is to be expected for the sprout number increased to form an arithmetic progression with seed size increasing ~~and~~ geometrically.

It is noteworthy that although prior to emergence from the ground, the individual sprout of small seed was utilizing a smaller amount of food material from the mother tuber, correlated with its slow development, it tended to make greater demands on the mother tuber during emergence and foliar development (It appears the mother tuber, small or large, has an important role/

Table V. Absolute loss of dry matter from the mother tuber g. per sprout per day

seed size	15/4-29/5	29/5-12/6	12/6-29/6	29/6-16/7
s	.005	.05	.043	.007
m	.009	.043	.067	.021
l	.015	.05	.081	.030

Table VI. Dry matter in the mother tuber at successive stages expressed as percentage of that at planting.

seed size	29/5	12/6	29/6	16/7
s	90.3	57.1	24.2	19.1
m	87.2	68.6	33.4	22.4
l	86.1	68.6	37.0	25.1

Table VII. The influence of seed size on the concentration of sugars.

(a) Reducing sugars (as glucose)

	(A) per 100 g. fresh weight				(B) per 100 g. dry weight			
	15/4	29/5	12/6	16/7	15/4	29/5	12/6	16/7
s	1.03	0.78	1.64	1.08	4.42	4.29	15.0	25.7
m	0.64	0.79	1.39	1.90	2.64	4.19	10.0	36.5
l	0.73	0.76	1.29	2.12	2.91	4.06	9.15	35.9
		(±.0489)						

(b) Sucrose

	15/4	29/5	12/6	16/7	15/4	29/5	12/6	16/7
s	.08	.21	.15	.10	.34	1.15	1.37	2.38
m	.11	.22	.16	-	.45	1.17	1.15	
l	.16	.21	.15	.12	.64	1.12	1.06	2.03
replicates	2	4	6	2	2	4	6	2

role to play during the formation of the photo synthetic apparatus). Limited resources in the small seed, however, did not permit a further rise in the rate of removal of food material from the mother tuber so that in the later stages, the ration available per sprout was less and less as the seed size decreased.

The relative rates of depletion: The dry weights at the successive stages are expressed as percentage of the dry matter at the start. (Table VI). The differences between the consecutive stage values are plotted against the mid point of the intervals between the successive stages. (Fig. 4D). These figures bring out clearly the initial slower rates of depletion in the small seed, as compared with larger seeds, but as soon as the sprouts were above ground, the position was reversed. High depletion all over occurred during the period 12/6/46 to 29/6/46, when the stolons and tuber initials were laid down. After June, the relative rate of depletion fell off rather rapidly in the small seed but gradually in the medium and the large seed.

The concentration of sugars in the mother tuber: That suppression of early development in the small seed associated with the slow depletion of the mother tuber was related to the factors other than soluble carbohydrates can be seen from Table VII A. The concentration of sugars per unit fresh weight was never lower in the small seed as compared with the medium and the larger seed, in the early stages.

Soon/

Soon after the emergence of the sprouts from the ground the leaves began to expand. Concurrently, there was a characteristic rise in the concentration of sugars all over and specially so in the small seed, in conformity with its higher rate of depletion during this phase. Towards the middle of July sugar concentration fell to normal values in the small seed but rose to as high as 2% in the large seed as well as the medium seed.

It is interesting to note that when the plant has well-expanded leaves, the concentration of sugars is higher in the mother tubers than it is during the earlier stages. This becomes still more significant if the sugars are expressed per 100 gms. of dry matter rather than per 100 gm. of fresh weight (Table VII. B) Again, it is noteworthy that the sugars increase in spite of rising temperatures and increase in the water content of the tubers, both of which are known to decrease the sugar content (e.g. Hopkins,1924.) A reference to Fig. I would reveal that both day and night temperatures were higher in June than at planting.

It may be argued that the higher concentration of sugars may not necessarily be related to higher plant requirements but to the failure of the sugars produced through diastatic activity to migrate to the plant organs on account of the limiting influence of some factors on the top growth. For example, in the present case, it may be put forward that since thestudies on mother/

mother tubers were made under un-manured conditions, nitrogen may have acted as a limiting factor on growth and may thus have interfered with the adequate removal of sugars at a rate consistent with its release through diastatic activity. But the fact that the dry matter continued to be lost by the mother tuber throughout the month of June and later, shows that (ignoring respiration losses) sugar concentration rose in spite of higher depletion rate and suggests that the two were related. It is all the same possible that at higher levels of nitrogen, the depletion of dry matter and sugar concentration may show a different relationship. This was investigated in the succeeding season and will be referred to later.

The concentration of non-reducing sugars was small in proportion to that of the reducing sugars. Furthermore, the non-reducing sugars showed some variation with seed size. They seemed to increase with increase in seed size and also with the onset of sprouting. In this connection, the observations of Denny (1930) are note-worthy. He found that sucrose is low in the dormant tubers and the chemical treatments which break dormancy raise the sucrose concurrently. It may, however, be noted that the actual quantity of sucrose involved is so little that its role in sprouting is incidental rather than critical.

While the percentage of total sugars did not decrease with the decrease in seed size the total content per tuber must do so as a sure consequence of reduced size. Thus/

Thus not only there are greater reserves at the disposal of the sprouts from the large seed but also the mobile sugars in a readily assimilable form.

Replanting the mother tuber:

The dry matter contents of the three seed sizes towards the middle of July were 1.3, 3.6, and 7.7 g. per tuber respectively. Thus the large seed had even at this stage more dry matter than what the small seed had at planting, and the medium seed had about half as much as the large seed. There was also evidence of the presence of soluble sugars in high concentration. Qualitative tests for starch (I_2K.I.) also revealed that there was plenty of starch present in the large seed. Medium seed gave a weak test and the small seed weaker still. Despite high water content, the old tubers were firm and healthy.

Two old tubers from each of the three sizes were replanted on 24-7-46 in small pots filled with garden compost, to see if the food material in them could sustain a fresh healthy plant. The soil was well supplied with moisture but there was no sign of the emergence of sprouts by the middle of August. The pots were emptied out. It was interesting to observe that while the small and the medium tubers had rotted away, the large ones reproduced themselves into small new tubers borne on thin tiny filament-like out-growths arising from the mother tuber.

Something appeared to inhibit the sprout vigour from the replanted large tuber, inspite of sufficient food/

food reserves. As the sprouts did produce rootlets and could draw nutrients from the soil, it is unlikely that the mineral matter was limiting. The food store in the tuber was undoubtedly unbalanced and it is tempting to assume that the growth-regulating substances may be deficient. The direct proof of this assumption will, however, come when it is possible to re-induce sprouting by the application of a suitable growth hormone.

This experiment may, however, be taken to furnish evidence that, after a plant is set up to carry on its independent existence, some of the extra food store of the mother tubers is utilized in laying down stolons and new tuber initials or other underground parts and takes little <u>direct</u> part in the top growth. As the surplus left over is proportional to the size of seed, the large seed can discharge this function relatively earlier and more effectively than the small seed.

<u>Height</u>.

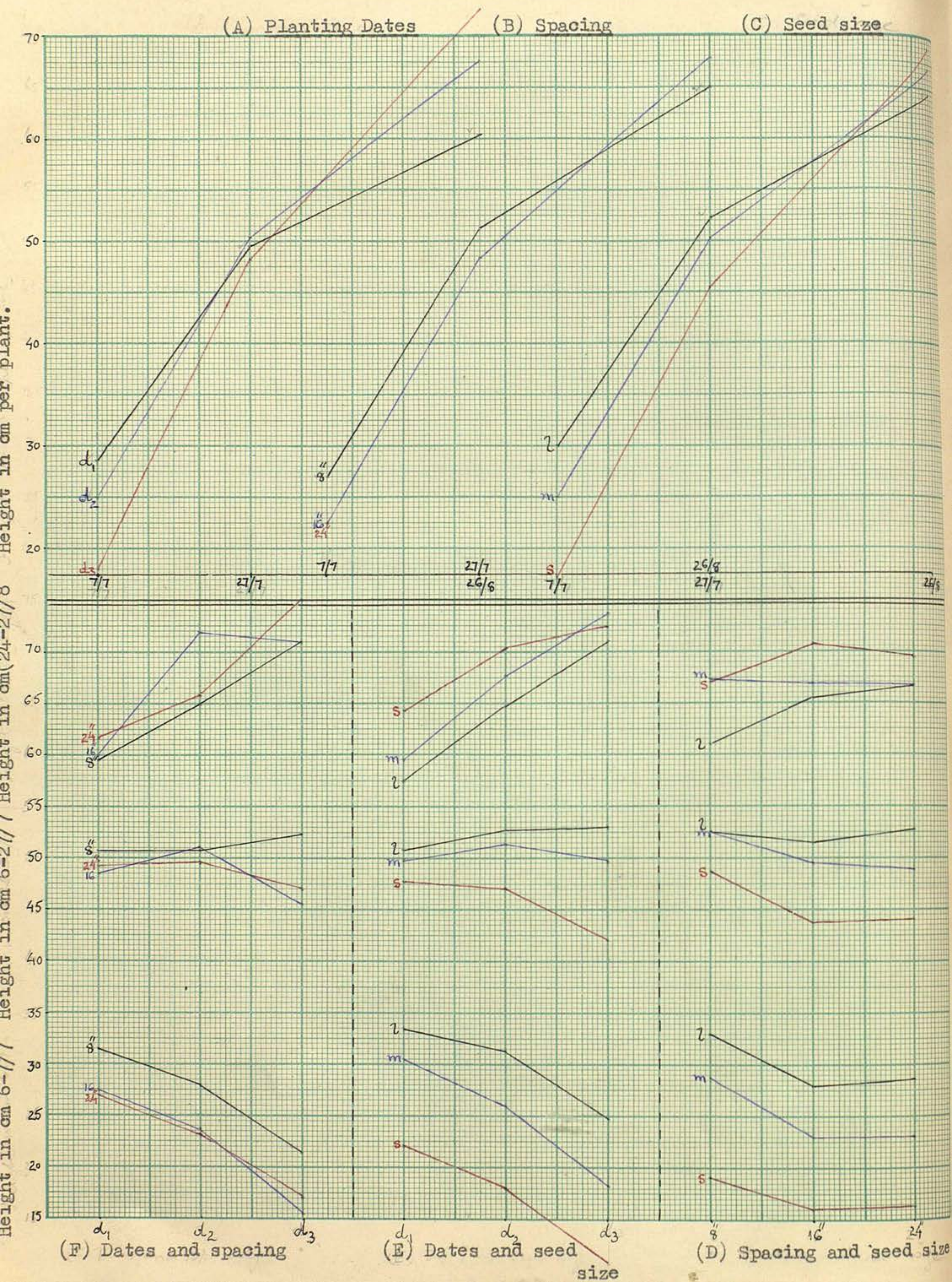
The analysis of variances are set out in table VIII for the three dates on which height was taken in the main experiment. The main effect of all the three factors, planting date, spacing and seed size was significant at the first stage of measurement. At the second stage, the effect of dates was subdued but that of spacing and seed size was still well marked and also tended to vary with the planting time as judged from the significant interactions, Spacing x Dates and seed size x Dates. Finally, the effect of spacing/

Table VIII Analyses of variances.

Height.

Due to	d.f.	6-7/7 mean square	6-7/7 F	26-27/7 mean square	26-27/7 F	24-27/8 mean square	24-27/8 F
Replicates	3	72.5		2518.1		24609	
D	2	66369.0	136.6^{xx}	2445.1	3.4^{x}	83627	15.1^{xx}
Sp	2	15786.1	32.5^{xx}	6332.0	9.0^{xx}	4921	
D.Sp	4	404.1		2573.1	3.6^{x}	6177	
Error (a)	24	485.9		700.2		5551	
Main plots	35						
Sub Blocks (within replicates)	8	853.0		1098.5		4202	
Ss	2	94583.4	426.3^{xx}	27332.1	60.8^{xx}	12060	6.1^{x}
Ss.xD	4	682.1	3.1^{x}	3266.7	7.3^{xx}	2508	
Ss.xSp	4	506.4	2.3	1421.3	3.2^{x}	2643	
Ss.xDxSp	8	287.2		353.0		1637	
Error (b)	46	221.8		449.3		1985	
sub-plots	107						

Fig 5. TREATMENT EFFECTS ON HEIGHT (1946)



spacing paled into insignificance but that of dates and seed size remained significant. The 'analyses of variances' do not indicate ~~of~~ the direction of effects and their magnitude in customary units. For this, the generalized effects of the three factors are presented in Fig. 5 A-C and the differential behaviours of the factors in pairs, in Figs. 5 D-F.

<u>Dates and height:</u> On $\frac{6}{7}$ July the height of plants under the three plantings was in the order of their planting date, and was brought out unmistakably even by visual observations. This is to be expected for plant growth can be reasonably supposed to be related to age which at the first stage was 88, 68, and 48 days respectively in the successive plantings. At the second stage, strangely enough, the three plantings tended to become level with one another. The second planting actually excelled the other two. At the third stage, the rather unexpected result of inverse relation of growth to age was recorded so that the height of plants fell uniformly in the direction $d_1 < d_2 < d_3$. It was about the second stage that the curves moved. Treatment effects in the end, therefore were mirror images of the initial trends.

<u>Spacing and height:</u> At the first stage, the plants under 8" spacing were taller than the widely-spaced ones by 4.5 cm. per plant. (Fig.5B). The differences narrowed down to 3 cm. at the second stage, and were made up in due course of time. Eventually, the widely spaced plants out-stripped the closely-spaced ones. Once/

Once again, the ultimate height was inversely related to the height in early stages. Throughout, the plant heights under 16" and 24" spacing were not perceptibly different and their curves overlapped, loath to separate.

<u>Seed size and height:</u> To start with, heights were directly related to the size of the seed planted. (Fig. 5C). Thus, not only were there fewer sprouts per tuber as the seed size declined but each was elongating at a slower rate in the early stages. The effect could not be wholly ascribed to delayed sprouting or age in terms of aerial existence, for the differences were of a higher order than the differences in the age would suggest (cf. seed size effect with planting time effect at this stage). By the end of July, the plants from small seed had made up much leeway, yet they stood in the same order $s < m < l$. Later, the rate of elongation fell off more rapidly in the plants from larger seeds as compared with the smaller seeds, and reversed the position of seed size with respect to height.

<u>Interaction: spacing and seed size:</u> The seed size effect did not vary with the spacing at the first stage, as seen from the parallel run of the curves (Fig. 5D). The close spacing increased height, so did large seed, and when together their effects were additive. Either of the two factors operated through an increase in the number of sprouts, which means reduced light intensity. Besides large seed assured more nourishment per sprout.

In mid-season, the effect of seed size decreased progressively/

progressively with decrease in spacing. Plants raised from medium seed were getting level with those from large seed, more and more as the spacing narrowed. The plants from small seed were also catching up in the same order. Thus the effect of reduced light intensity in increasing height under crowded conditions, inclined to be nullified by some sort of internal competition, operating in the reverse direction.

Late in the season, interesting trends in the treatment effects developed. The competition became so acute in the plants from large seed under close spacing that both the small and the medium seeds excelled them in height. With 16" and 24" spacing (less competition) the medium seed equalled the large in height and the small seed showed further increases in height. Thus the nine treatments fell into 3 groups:

Acute competition and low height	Balanced conditions medium height	Least competition maximum height
8" l	16"l,24"l,8"s 16"m,24"m,8"m	16"s,24"s.

The large number of treatments in the intermediary height group as seen in the above diagram indicates how the two opposing tendencies resulting from more sprouts per hill (light intensity and competitive effects) balanced to produce a particular result over a range of conditions. With wider departure from it alone clear-cut effects of competition were exercised.

Interaction: Dates and seed size: The variation in height caused by seed size diminished with age, as seen/

seen from the narrowing down, of the height differences produced by seed size, with time as well as with early planting (= age effect) (Fig. 5E). Finally, the inverse relation between seed size and height obtained only in the early plantings.

<u>Interaction: Dates and spacing:</u> At the first stage, the effect of close spacing in raising the stature of plants was uniformly recorded in the three plantings i.e. on plants of different ages. (Fig. 5F). This means, whatever effect was produced early by close spacing, that was maintained over a period of time (cf. ~~and~~ seed size effect). This is further confirmed by the fact that in d_3 (third planting) the early spacing effect was carried on up to the second stage, when, however, it was greatly reduced in the first two plantings. Thus the modifying effect of age emerged in due course of time. Finally, the plants under 8" spacing were, as a whole, shorter in stature as compared with the two wider spacings, which between themselves did not fall into regular series.

<u>Node number and Internodal length:</u> Nodal counts were taken from one replicate from the plants measured for height at the final stage, and from the two sets of readings, the mean internodal length was computed. An estimate of error was obtained from the high order interactions (Yates, 1937) in the 'analysis of variance' (Table IX). Summarised effects are given in Table X.

Evidently, delayed planting increased height through the expansion of the internodes (extension growth) but not the number of nodes (meristematic activity.) The converse was true of spacing or seed size, where the number/

Table IX Analyses of variances

Due to	d.f.	Node Number Final mean square	F	mean Internodal length mean square	F
D' (Linear)	1	0.5		1.6320	8.58^{x}
Sp' (Linear)	1	1530.9	22.3^{xx}	.0040	
$D' \times Sp'$	1	243.0		.1240	
D'' (Quadratic)	1	1.5		.3716	
Sp'' (Quadratic)	1	216.0		.0189	
Remainder (= error)	3	68.68		.1898	
Main plots	8				
Sub. Blocks	2	377.5		.0094	
Ss' (Linear)	1	1120.2	21.0^{xx}	.0242	
$Ss' \times D'$	1	18.7		.00001	
$Ss' \times Sp'$	1	36.7		.0261	
Ss''	1	112.6		.00125	
High order interactions (= error)	12	53.33		.0299	

Table X Treatment effects on the components of Height

	mean node number		mean Internodal length	
$\underline{d}_1$	18.8	$\pm .384$	3.47	$D' = 0.6^{xx} \pm .206$
$\underline{d}_2$	18.8		3.52	$D'' = 0.5 \pm .36$
$\underline{d}_3$	18.9		4.07	
8" in	17.4	$Sp' = 2.3^{xx} \pm 0.542$	3.65	$\pm .145$
16" in	19.3	$Sp'' = -1.5 \pm 0.94$	3.72	
24" in	19.7		3.68	
$\underline{s}$	20.0	$Ss' = 2.0^{xx} \pm .43$	3.64	$\pm .058$
$\underline{m}$	18.5	$Ss'' = 1.0 \pm .74$	3.70	
$\underline{l}$	18.0		3.72	

Table XI Variations in the internodal length up the stem as affected by cultural treatments (calculated from the successive internodal lengths measured finally).

mean internodal lengths (32 plant averages) in cm.

	Basal 3	Next 3	middle	Penultimate 3	last 3
$\underline{d}_1$	1.6	3.8	5.1	5.0	2.8
$\underline{d}_3$	2.2	3.9	5.9	5.8	2.7
8 in	2.1	4.3	5.7	5.2	2.6
24 in	1.7	3.4	5.3	5.6	2.9
$\underline{s}$	1.5	2.8	5.4	5.6	2.9
$\underline{l}$	2.3	4.9	5.6	5.2	2.6

number of nodes was the determining factor. This is however a case where averages are misleading. In the early part of the season, wide spacing as well as ~~large~~ small seed produced plants with short internodes (Light effect) (Table XI). Later, due to enhanced assimilation resulting from more light, water and nutrients per individual, these very conditions were characterised by longer internodes and prolonged growth-activity. The later expansion cancelled out the early diminution of internodes, so that the mean internodal length was unaffected. The prolonged growth enabled the production of more nodes, in case of small seed or wide spacing, and reflected differences in height.

The effect of late planting on the extension phase of growth was recorded over all parts of the main axis. It thus obtained throughout the growth cycle in general. Expansion of cells is largely controlled by the water factor (Crowther, 1934), Dastur and SINGH, 1943). Late planting could be expected to profit more than the early in regard to the vegetative growth from the mild and wet weather in July and August in 1946. This is because the former was in the growing condition when the latter was actively tuberising and the effect of water on the extension growth would depend on the stage of plant development. This explanation, however, does not provide for the longer internodes in the late planting in the early stages and in a year of low or medium rainfall. A reference should be made to the 1947 results in this connection.

The ability of late planting to make up in node-production and/

and thus equal the early planting despite age differences, is amazing. There was distinct evidence of prolonged growth activity in the deferred planting.

The size of leaves: A study of node number and the length of internodes under varying conditions at different stages of plant growth is important not only in understanding the effect on the apical growth but also in the relation of the two components to the number of leaves (per sprout) and their size. Thus the plants from small seed or wide spacing had smaller size of leaves to start with, as compared with those from large seed or close spacing. With the advance of season the internodes expanded in the former, and so did the leaves. Similarly, the late planting was characterised by larger foliage. These observations were also supported by quantitative observations but the data was inadequate for a complete analysis.

General observations on flowering and maturity.

The variety Gladstone flowers profusely. Quantitative records were not maintained on flowering. Visual observations revealed that flowering was delayed by 7-10 days for every delay in planting by 20 days i.e. the flowering was delayed in the plantings to the extent of their delay in emergence. The plants from large seed came into flowering earlier than those from the medium or the small seed, with about week's difference between the extreme seed sizes.

Foliar activity, apical growth and flowering all pointed to the distinctive effect of the factors on maturation./

maturation. To give a quantitative expression to the differences in maturity, a system of assigning marks to the different plots on a scale of 1-5 (rising by a half mark) was adopted on the basis of general maturity symptoms, on 5-9-46. A decrease in seed size, delay in planting and wide spacing, individually delayed maturity and their effects were additive.

Dry matter changes of the vegetative parts.

Seed size effect in the early stages: At emergence the weights of the sprouts were almost proportional to the size of the tuber planted (Table XII). Besides, the individual sprout was stouter as the seed size enlarged. This no doubt arose from the early development of sprouting in the large seed and their relatively early rooting. When the sprouts expanded their foliage and then began to photo-synthesise, the seed size effect on the sprout vigour continued in the same direction but the magnitude of difference gradually went down, so much so that on 29 June there were little differences in the dry matter per sprout from the different seed sizes. The differences per plant, however, persisted.

It would appear that the greater height of individual sprout arising from large seed, as measured on 6-7-46 (see Fig.5) was not in keeping with the absence of any such superiority in favour of large seed in the dry matter per sprout. It may, however, be recalled that greater height in large seed was mainly due to the extension of internodes and not to the greater number of nodes (or number of leaves per sprout) and/

Table XII <u>The effect of seed size on dry matter in early stages (vegetative parts.)</u>

	Dry matter per hill			Dry matter per sprout		
Dates	29/5	12/6	29/6	29/5	12/6	29/6
Seed size						
s	0.35	1.39	8.60	0.10	0.41	2.7
m	0.76	2.56	12.8	0.15	0.50	2.6
l	1.33	4.14	16.3	0.17	0.54	2.3
S.E.	±.073	±.144	±.88			

Table XIII. <u>The effect of seed size and spacing on growth (as sampled on 16-7-46)</u>

(a) Dry wt: per plant (g)

	8 in	16 in	24 in	mean (±1.40)
s	31.3	33.9	42.2	35.8
m	32.0	51.6	50.6	44.7
l	34.0	52.4	69.5	52.0
mean (±2.02)	32.4	46.0	54.1	

(b) Dry wt: per sprout (g)

	8 in	16 in	24 in
s	9.4	12.1	14.7
m	6.6	10.7	10.2
l	5.6	8.1	10.6

(d) Dry wt: per sq: yd: (g)

	8 in	16 in	24 in	mean
s	188	102	84	125
m	192	155	101	149
l	204	157	139	167
mean	195	138	108	

(c) Height (cm) comparable figures

	8 in	16 in	24 in
s	37.3	34.2	33.5
m	43.2	37.9	39.4
l	42.7	42.0	41.8

and thus individual sprouts of different seed sizes may approach in dry matter, despite wide disparity in height.

<u>The effect of seed size and spacing</u> (later stages): The vigour of sprouts arising from small seed further improved towards the middle of July so much so that when the dry matter per plant is considered, the small seed compared favourably with the medium and the large seed under close spacing (Table XIII). Under wide spacing, however, the compensation was still inadequate.

The lag between the effect on the two growth indices, height and dry matter, is again to be noted (cf. Tables XIIIb and XIIIc). This is explicable in terms of the differential behaviour of light on height and dry matter production. Dry matter decreases but height increases with reduced light intensity till such time as the indirect effects of low light intensity limit the elongation of the shoots.

The data in Table XIIIa are an excellent illustration of the operation of the principle of limiting factors. The expression of seed size influence was completely suppressed with close spacing (competition for light and nutrients) and gradually manifested itself with the increase in spacing.

As to the effect of wide spacing on dry matter the individual sprout or plant grew vigorously with increase in spacing but, when the dry matter was considered on area basis, the plots with thin stand were still behind the progressively densely-populated plots. Thus the recovery/

recovery was inadequate, even under the large seed size, to annul the reduction in plant number.

By the end of July, the vigour of the individual sprouts from small seed was sufficient to offset the initial disadvantage of fewer sprouts per tuber, not only under 8" spacing but also under 16" spacing (Table XIV). Nevertheless, increasing seed sizes were still leading under 24" spacing. Regarding spacing effect, the plants under 16" spacing irrespective of the seed size developed compensatory growth enough to get level with double the population on area basis. The plants with 24", too, belonged to the same category provided the seed used was large. Compensation, however, still lagged behind in the plants from the small and the medium seed planted at 24" spacing. But, the operation of the same mechanism of compensation brought these two treatments also to the general dry weight level over the rest of the treatments (Table XV) in the end of August.

Form of growth.

The nature of adjustment by which sprouts from small seed making apparently a poor beginning but gradually getting near those with a better start in life, can be understood in terms of seed size influence on the growth habit of the plant. The way by which the fewer individuals per unit area (i.e. wide spacings) make up for their initial handicap, is also explicable in terms of the spacing effect on the morphogenic development of the plant.

Mention/

Table XIV. Seed size and spacing effects on dry matter (sampled on 30-7-46)

	Dry matter per plant (g)				Dry matter per sq: yd: (g)		
	8 in	16 in	24 in	mean (±3.76)	8 in	16 in	24 in
s	36.5	70.2	68.6	58.4	219	211	137
m	38.2	61.3	77.1	58.9	229	184	154
l	35.1	71.3	103.0	69.8	211	214	206
mean (±3.68)	36.6	67.6	82.9				

Table XV. Seed size and spacing effect on dry matter (sampled on 30-8-46)

	Dry matter per plent (g)				Dry matter per sq: yd: (g)		
	8 in	16 in	24 in	mean (±4.94)	8 in	16 in	24 in
s	38.6	77.0	94.2	69.9	232	231	188
m	35.4	66.6	105.7	69.2	212	200	211
l	37.3	84.3	120.7	80.8	224	253	241
mean (±4.65)	37.1	76.0	106.9				

Table XVI. Influence of seed size and spacing on Root/shoot ratio

	12/6		16/7			30/7		
			8 in	16 in	24 in	8 in	16 in	24 in
s	50.3	s	11.5	10.4	9.3	9.8	7.2	7.5
m	52.4	m	14.0	11.9	10.8	12.4	9.5	8.9
l	61.0	l	17.3	13.0	11.9	14.4	10.9	8.9

Mention has already been made of the elongation of the internodes in the mid-season and later and the corresponding increase in the size of the leaves, under conditions of less competition i.e. where the seed size was small and the spacing wide. Another mode of compensation was a profuse axillary development near ground level where the internodes were shorter under these conditions, in particular. The analogy between this effect and tillering in cereals may be noted. Any factor which restricts the elongation of internodes in early stages endows the plant to bounce with an efficient shoot system.

It was also observed that during the period of active growth a bud near the apex in most of sprouts under conditions of less competition was stimulated, developed rapidly, giving rise to a bifurcation of such sprouts. There was thus a distinct leaning on the part of the plant to make use of the available space and furnish an efficient light trap. The axillary development was reflected in the relatively later maturity of the plants under wider spacing as well as large seed, and enabled them to produce more leaves all over, as well as at the main axis, recorded earlier.

It must, however, be realized that these compensatory mechanisms in growth, tending to improve the status of plants with a poor beginning, must have proceeded at the expense of some other plant organ or organs.

<u>Root/shoot ratios</u>: Striking differences in the root/

root ramification between the plants from the small and the large seed were observed at sampling. The large seed plants possessed an extensive root system. Bulk of the effect was, however, due to early emergence and more sprouts per seed tuber. But even when root (plus stolons)/shoot ratio was worked out, the differences were convincing (Table XVI). The underground development seems to be formed relatively early and to a relatively greater proportion than the top growth, by the large seed.

<u>The number of tubers:</u>

The inspection of results for tuber number revealed that the effect of treatments appeared relatively early and the same trends were maintained over the period covered by sampling. Curiously enough, the general mean did not increase with the passage of time but rather tended to decrease. The anomalous decrease was probably due to the fact that last two stages of sampling occurred on wet days and some of the tubers were probably lost in wet soddy soil. The important point remains, that the tubers did not increase in number with time and most of them were set relatively early. The number that set depended upon the size of seed. (Table XVII). The increase in spacing caused very little further improvement although this too was statistically significant. The controlling influence of the increase in the size of seed was basically due to the greater number of under-ground points available for stolons to arise, on account of/

Table XVII. The effect of seed size and spacing on the number of tubers (pooled estimate).

(a) per plant in g.

	8 in	16 in	24 in	mean (±.705)
s	10.1	10.5	9.8	10.1
m	13.9	16.8	15.0	15.4
l	16.0	18.3	19.1	17.8
mean (±.373)	13.3	15.2	14.6	

(b) per sq. yd. in g.

	8 in	16 in	24 in	mean
s	60.6	31.5	19.6	37.2
m	83.4	50.4	30.0	54.6
l	96.0	54.9	38.2	63.0
	80.0	45.6	29.3	

Table XVIII. The spread of tubers in space under 24 in. spacing

(a) Tuber number per plant

Distance from the plant

Seed size	±4 in	±6 in	±8 in	±12 in
s	11.4	13.4	13.75	13.95
l	15.6	18.15	18.65	18.85

(b) Percentage distribution

Distance from the plant

Seed size	±4 in	±6 in	±8 in	±12 in
s	81.7	96.0	98.5	100
l	82.7	96.2	98.8	100

Table XIX. Development of the size of tubers under different spacings and seed sizes. (gm. per tuber)

Seed size	16/7	30/7	30/8
s	10.8	34.7	96.3
m	10.9	27.4	70.9
l	10.1	28.0	61.7
S.E.		±2.50	±2.61

Spacing	16/7	30/7	30/8
8 in	9.4	24.6	53.4
16 in	10.3	31.1	~~73.8~~ 77.1
24 in	11.9	34.4	98.4
S.E.		±2.20	±5.39

of more sprouts per seed. This is in accord with the suggestion of Bates (1935). The correlation coefficient between the number of sprouts and the number of tubers was significant ($r = +0.60$[x]). The setting of the potential bearing points is assured early by the surplus food contained in the mother tubers after the plant is set up.

Relatively small effect of wide spacing on compensation through the number of tubers arose from the fact that the bulk of the new tubers congregated near the plants. This was observed at sampling and was later confirmed on 16-10-46. The distribution of potatoes in space was determined by taking counts with increasing distance from the plants on either side. 80% of the tubers were localized within 8" (±4") of the plant and 95% within 12" (±6"). Only 5% or so lay outside this range (Table XVIII).

As the improvement in the tuber number per plant was very small as the spacing widened, the tuber number per unit area fell steeply as the plant population decreased (Table XVIIb).

<u>The size of tubers:</u>
Treatment effects on tuber size were inversely related to those on the number of tubers, and developed gradually to offset in yield, at least partly, the effect of reduction in the tuber number caused by small seed and wide spacing. Spacing effect on tuber size appeared as early as mid July and developed with time. (Table XIX). Seed size effect came on slowly. The determining factor/

factor in the speed of compensation was the extent to which the depression in the number of tubers occurred under particular conditions.

The conditions responsible for the production of few tuber-bearing stolons per unit of available resources (in small seed and in wide spacing) enable the plants to make less demands on the elaborated foods, so that relatively more is spared for top growth, giving the plants a chance to recoup in vegetative vigour. (The word 'competition' loosely applied in some of the discussion in the preceding pages, refers to the internal competition for metabolites between the vegetative and the storage organs). The extra growth in turn manufactures more and more metabolites, a portion of which is utilized for further growth and the rest, for storage. If the number of tubers increase in proportion as the extra food material is made available, the influence on the size of potatoes would not exist. The extra food material is monopolized by the tuber-initials already set and this monopolization does not permit a substantial increase in the number of tubers (another case of internal competition). The tubers already laid down are limited and the excess food is monopolized almost wholly by the comparatively fewer tubers which swell in size. Both the small seed and the widely-spaced plants produce a greater assimilatory surface per tuber and therefore the size of tubers in the new crop is favourably influenced.

<u>Percentage ware:</u>

The/

The effect of seed size and of spacing on the percentage ware calculated from the yields of the different grades in the produce, from the main experiment, was just a reflection of the effect on the size of the individual tuber (Table XX). The ware percentage was influenced more by spacing than by seed size despite the wider range covered in case of the seed size factor. This is so because the number of the sprouts plays the critical role by controlling the number of tubers. The seed size has to be one third or $\frac{1}{4}$ to produce the same effect on tuber number as produced by doubling the space per plant. Secondly, the later emergence of small seed acts as a set-back by reducing the time factor. The progressive increases in the ware percentage with the early plantings or the delay in lifting signify the role of time factor or the length of season in enlarging the size of tubers.

It is interesting to record that the percentage ware ranged from about 9.8% to 72.5% under the different conditions in this experiment. By suitable combinations of the different factors and their levels it is possible to get the desired result according to the interest from the commercial point of view.

The relative strength of the different factors in influencing the percentage ware in the produce can be judged from the two-way tables (No. XX). The factors operated independently in general so far as percentage ware is concerned. The effectiveness of late lifting, however, improved progressively with decrease in seed size.

Table XX. The effect of cultural factors on the percentage ware in the produce.

Planting dates		spacing		seed size		lifting time	
d_1 =	45.8	8 in =	20.9	s =	44.1	t_1 =	34.6
d_2 =	34.1	16 in =	37.9	m =	35.7	t_2 =	39.1
d_3 =	30.7	24 in =	51.8	l =	30.7		
S.E.	± .850		± .850		± .812		± .498

Dates and spacing

	8 in	16 in	24 in
d_1	28.9	46.3	62.2
d_2	16.6	36.4	49.2
d_3	17.2	30.9	43.8

Dates and seed size

	s	m	l
d_1	56.3	43.1	38.0
d_2	40.4	33.0	28.7
d_3	35.6	30.9	25.5

Seed size and spacing

	8 in	16 in	24 in
s	27.8	46.0	58.6
m	20.3	36.1	50.6
l	14.6	31.4	46.1

Seed size and lifting time

	s	m	l
t_1	40.7	33.6	29.4
t_2	47.5	37.8	32.0
Diff.	6.8	4.2	2.6

S.E. of the body of 3 x 3 Sub-tables

Dates and spacing.............................. ± 1.472

Seed size...................................... ± 1.406

Inter action T.Ss' (linear) 2.1^{xx} ± .745

TREATMENT EFFECT on FINAL YIELDS.

Gross Yields of potatoes.

The main effects of all the four factors viz, planting time, spacing, seed size and time of lifting were significant on aggregate yield of tubers (Table XXI). The first-order interactions were much less important. Even when the interaction degrees of freedom were split up into single degrees of freedom some of these were only just significant at 5% level or were merely suggestive.

Main effects:- Planting time was the most potent factor determining the yield of the potato crop (No. XXII) The yield declined progressively but not proportionately with advancing planting date. An initial delay in planting by 20 days caused a smaller depression in yield than a further delay by the same period. The variations of yield in the successive plantings were comparable to their age in terms of aerial existence. The increase in plant population raised the output of new tubers. Here again the rise in yield was not proportional to the increase in the density of plants. It is important to note, for a correct evaluation of results, that the plant distances in the three spacings increased by equal 'steps' of 8", but the plant population per unit area was ~~increased~~ in the ratio of 2:3:6 in the wide, medium and the close spacing. There was thus a clear falling off in the effectiveness of the successive increments of plant densities.

The Aggregate yield was directly related to the size of the seed planted. As the three seed sizes did not form an arithmetic progression but the yields from them/

Table XXI Analyses of Variances.

Due to	d.f.	Gross Yield m.sq.	Financial Returns m.sq.	Ware Percentage m.sq.	Net seed m.sq.
Blocks	3	18612	367.92	475.76	2720.0
D.	2	313911^{xx}	7562.74^{xx}	4555.96^{xx}	45326.7^{xx}
Sp.	2	106151^{xx}	2701.02^{xx}	17229.26^{xx}	472977.2^{xx}
D.Sp.	4	7312	373.22	105.67	15806.4^{xx}
Error (a)	24	6276	178.22	52.04	1820.9
Main plots	35				
Subblocks	8	11450	318.89	71.52	1572.0
Ss	2	82088^{xx}	265.45^{x}	3307.21^{xx}	57645.1^{xx}
D. Ss.	4	3192	39.78	153.21^{x}	1910.8
Sp. Ss.	4	4305	494.15^{xx}	12.25	6958.8^{xx}
D.S.Ss.	8	1694	59.90	68.70	4786.6^{x}
Error (b)	46	2003	57.14	47.50	941.9
Plots	107				
T.	1	58115^{xx}	1192.86^{x}	1113.39^{xx}	1048.9
Error(c)	11	5876	197.39	26.84	2629.5
T.D.	2	982	25.93	15.64	87.6
T.Sp.	2	501	9.26	12.19	547.3
T.Ss.	2	2865	51.47	79.02^{x}	289.8
T.D.Sp.	4	1048	45.69	13.07	1377.6
T.D.Ss.	4	220	9.87	20.65	630.4
T.Sp.Ss.	4	1173	28.40	40.57	717.7
T.D.Sp.Ss.	8	1386	62.66	12.88	1784.0
Error (d)	70	1050	37.16	19.99	1083.8
Total	215				

Table XXII. The main effects of treatments on the yield of tubers (tons per acre).

Planting time		Spacing		Seed size		Lifting time	
d_1	15.2	8 in	14.8	s	13.0	t_1	13.4
d_2	14.2	16 in	13.8	m	13.8	t_2	14.2
d_3	12.0	24 in	12.9	l	14.7		
S.E.	±.229		±.229		±.129		±.181

Table XXIII. Treatment effects on the yield of potatoes (tons per acre)

(a) Dates and spacing

	8 in	16 in	24 in
d_1	16.50	15.27	13.85
d_2	14.95	14.40	13.23
d_3	12.85	11.69	11.56
d_1-d_3 (±.561)	3.65 xx	3.58 xx	2.29 xx

(b) Dates and seed size

	s	m	l
d_1	14.73	14.94	15.94
d_2	13.36	14.14	15.08
d_3	10.92	12.21	12.96

Table XXIV. Treatment effects on the yield of potatoes (tons per acre)

(a) Spacing and seed size

	8 in	16 in	24 in
s	13.95	12.88	12.19
m	14.90	13.43	12.96
l	15.44	15.05	13.49

(b) Seed size & time of lifting

	s	m	l
t_1	12.44	13.39	14.40
t_2	13.57	14.15	14.93
Diff.	1.13	0.76	0.53

(d) Spacing & time of lifting

	8 in	16 in	24 in
t_1	14.42	13.32	12.49
t_2	15.11	14.26	13.27
diff.	.69	.94	.78

(c) Dates and lifting time

	d_1	d_2	d_3
t_1	14.85	13.69	11.69
t_2	15.57	14.70	12.37
diff.	.72	1.01	.68

S.E. of body of the 3 x 3 tables:

Dates and spacing	±0.396
Seed size effect	±0.223

Interaction T.Ss (linear) 0.30 x ± .132

them rose by equal increments, there was again an evidence of the operation of the 'law of diminishing returns'.

Delayed lifting significantly increased the yield.

Dates and spacing: The early plantings gave better yields than the late one, irrespective of the spacing. (Table XXIIIa) Similarly the effect of close spacing was positive in each of the plantings. There was an indication, however, that the superiority of the early plantings was enhanced by close spacing. In other words, closer spacing worked at maximum effectiveness in the early planting. This is an interesting result and is contradictory to that obtained with other crops such as cotton where a late crop must be spaced close to maintain its yield (Gregory et al, 1932, Dastur and Singh, 1942). It appears close spacing is necessary for late planting of those crops which suffer in vegetative growth under late sowing. In the potato, the case is just the reverse. Here the late crop becomes unbalanced by a stimulation of the vegetation phase at the expense of the storage.

Dates and seed size:

The direction of the effect of planting date was not altered by a change of the size of seed ~~size~~ and vice versa (Table XXIIIb).

It is interesting to note that the yields of d_3l and d_2s compare favourably and, similarly, those of d_2l and d_1s agree closely. It is suggestive therefore that the reduction in the yield from small seed was proportional/

proportional to its delay in emergence from the ground.

Seed size and spacing.

Table XXIVa shows that the two factors were analogous in behaviour and therefore interchangeable. The treatments fall into 5 groups as shown by the dotted diagonal lines.

Time of lifting in relation to other factors:

Curiously enough, the later plantings did not profit any more than the early planting, from the delay in lifting (Table XXIVc). Possibly the incidence of blight masked the expected result. Similarly, all the spacings derived the same benefit from late lifting. The interaction of lifting time with seed size was however significant. (Table XXIVb). The response to lifting time declined with increase in the size of the seed planted.

Planting date and the level of manuring: The behaviour of planting time was also studied under unmanured conditions, on a small scale, in a simple experiment, with three plantings replicated thrice. medium seed was planted at a uniform distance of one ft. between sets. The size of plot was 13½' x 25' after the rejection of borders.

The effect on yield was interesting. The Linear component was insignificant but the quadratic was highly significant. (Table XXV). The yield had an optimal value round the central planting (30th April). The last planting was as good as the first, contrary to the progressive decline in yield with delay in planting/

Table XXV The influence of planting time on yield in relation to the level of manuring.

Tons per acre.

Under unmanured conditions			Under manured conditions (main Expt:)		
d_1	10.07	$D' = .03 \pm.53$	d_1	15.21	$D' = -3.18^{xx} \pm.32$
d_2	11.50	$D'' = -2.83^{x} \pm.92$	d_2	14.19	$D'' = -1.14^{x} \pm.55$
d_3	10.10		d_3	12.03	
S.E.	$\pm.37$			$\pm.23$	

Table XXVI Main effects of the Factors studied on the yields of the grades of produce, total yield and the net yield.

	Ware %	Yield in tons per acre. ware	Gross seed	(net seed)	chats	Total yield in tons per acre. Gross	net
	($\pm$.85)		($\pm$.123)			($\pm$.23)	
d_1	45.8	6.87	8.22	(6.92)	0.11	15.21	13.90
d_2	34.1	4.74	9.33	(8.03)	0.12	14.19	12.89
d_3	30.7	3.62	8.31	(7.01)	0.10	12.03	10.73
	($\pm$.85)		($\pm$.123)			($\pm$.23)	
8"	20.9	3.15	11.44	(9.31)	0.18	14.77	12.63
16"	37.9	5.30	8.40	(7.34)	.09	13.79	12.73
24"	51.8	6.78	6.03	(5.32)	.06	12.87	12.17
	($\pm$.81)		($\pm$.089)			($\pm$.13)	
s	44.1	5.81	7.12	(6.55)	.07	13.00	12.44
m	35.7	4.92	8.73	(7.52)	.11	13.76	12.55
l	30.7	4.50	10.02	(7.89)	.14	14.66	12.53
	($\pm$.50)		$\pm$.121			($\pm$.18)	
t_1	34.6	4.62	8.68	(7.38)	.11	13.41	12.11
t_2	39.1	5.54	8.57	(7.27)	.12	14.22	12.92

planting under manured conditions. Though no strict comparisons are possible, it is highly suggestive that the earlier plantings responded more to the fertilizer treatment and contributed to their superior behaviour.

<u>The yield of the different grades and the net yields:</u>

A study of the influence of the different cultural treatments on the different grades is necessary from the point of view of the seed potato trade. Since some of the treatments entail extra investment in the form of the seed requirements, it is necessary to evaluate the net seed (i.e. Total seed obtained <u>minus</u> seed used at planting) produced under those conditions. It would then reveal the relative importance of the different factors in the potato Industry and give an idea of the economic returns under different conditions. (Tables XXVI-XXX) Reference may be made to Table XXI for the 'analysis of variance'.

<u>Planting date:</u> The yield of ware decreased progressively though not proportionately with delay in planting. (Table XXVI) The seed fraction had, however, the optimal value at the central planting. There was thus indication of a substantial quadratic response. The chats contributed very little to the total yield under any condition. The yield trends with change in planting time were determined by the 'ware' in the produce, to a large measure. The later plantings were successful in carrying the bulk of their chats into the 'seed' grade but/

but not from the seed into the ware grade.

Spacing: The amount of 'ware' produced declined with increase in plant population, but that of 'seed' increased considerably. Even when allowance for extra seed used in closer planting was made, the net yield of seed was related to spacing rising by two tons per acre for every decrease of spacing by 8" between setts. Much of the beneficial effect of close spacing on gross yield was absorbed by the extra seed requirements and therefore net yields showed smaller disparity in yield. Still the balance was in favour of 16" and 8".

Seed size: The effect of seed size on different grades of produce was of a lower order than that of spacing despite a wider range covered in the levels chosen for this factor. The direction of effect was, however, the same.

The 'ware' decreased steadily as the seed size enlarged but the seed fraction increased to a greater extent. When the seed weights used at planting were deducted from the new 'seed', the balance was still in favour of the large seed and the medium seed treatments. In the net yield, the increasing seed fraction and the decreasing ware, as occasioned by the rising seed sizes, squared up neatly so that net yields were unaffected by the seed size factor.

It may be noted that the close spacing as well as large seed was conducive to the introduction of more chats in the produce.

Time of lifting: The extra yield through delayed lifting/

lifting was wholly contributed by the 'ware grade.

Dates and spacing: The effect of close spacing in increasing the total or the net seed in the total produce was of a higher order in case of the April plantings than the May planting. (Table XXVII). Spacing effect in the form of decrease in Ware was only slightly more pronounced under the earlier plantings. It thus appeared that the best combination in seed producing areas was early plantings with spacing on the closer side of 16" between setts.

Seed size and planting time: The effects of seed size on the different grades were not modified by a change of planting time and the net yields were maintained over a wide range of seed size, in the early as well as the late planting. (Table XXVIII).

Seed size and spacing: The comparative value of the two factors, spacing and seed size, on the different grades of produce can be seen from Table XXIX. Spacing was more potent for seed production than seed size. In areas unfit for seed production there is no reason why spacings even wider than 16" could not be adopted or the use of seed as small as 1 oz. per tuber or even smaller or the large seed after cutting should not be encouraged. In seed-producing areas closer spacing holds out greater promise with small and medium seed. The use of very close spacing with large seed was definitely risky for the net yield dropped off to low values, mainly on account of the reduction of ware, under these conditions of acute competition./

Table XXV11. <u>The effect of planting date and spacing on the grades of produce and the net yields (Tons per acre).</u>

	Ware			Seed			Net seed			Net yield		
	8 in	16 in	24 in	8 in	16 in	24 in	8 in	16 in	24 in	8 in	16 in	24 in
d_1	4.78	7.09	8.75	11.55	8.08	5.04	9.42	7.02	4.33	14.37	14.21	13.14
d_2	2.47	5.22	6.54	12.28	9.10	6.62	10.15	8.04	5.91	12.82	13.34	12.52
d_3	2.19	3.60	5.06	10.48	8.01	6.44	8.35	6.95	5.73	10.72	10.63	10.85

Table XXV111. <u>The effect of planting time and seed size on the grades of produce and the net yields (Tons per acre).</u>

	Ware			Seed			Net seed			Net yield		
	s	m	l	s	m	l	s	m	l	s	m	l
d_1	8.22	6.41	5.99	6.44	8.42	9.81	5.87	7.21	7.68	14.16	13.73	13.82
d_2	5.36	4.62	4.25	7.92	9.42	10.66	7.35	8.21	8.53	12.79	12.93	12.95
d_3	3.86	3.75	3.25	7.00	8.36	9.58	6.43	7.15	7.45	10.35	11.0	10.83

Table XX1X. The effect of spacing and seed size on the grades of produce and the net yields (Tons per acre).

	Ware			Seed			Net seed			Net yield		
	8 in	16 in	24 in	8 in	16 in	24 in	8 in	16 in	24 in	8 in	16 in	24 in
s	4.01	6.15	7.27	9.82	6.67	4.87	8.89	6.21	4.56	13.02	12.42	11.88
m	3.13	4.94	6.71	11.60	8.41	6.19	9.62	7.42	5.53	12.92	12.44	12.30
l	2.30	4.82	6.37	12.90	10.11	7.04	9.42	8.37	5.88	11.96	13.31	12.33

Table XXX. The effect of lifting time in relation to seed size.

	ware (tons per acre)				seed (tons per acre)		
	s	m	l		s	m	l
t_1	5.13	4.50	4.23	t_1	7.23	8.78	10.03
t_2	6.49	5.35	4.77	t_2	7.01	8.69	10.00
Diff.	1.36	0.85	0.54		-0.22	-.09	-0.03

The best combination from the point of view of the net seed as well as the net yield were 16"l, 8"s, 8"m, according to this particular experiment.

<u>Lifting time and seed size:</u> The significant variations in the profitablenessof delayed lifting, with the different seed sizes, occurred on the ware in the produce (Table XXX~~0~~) reflecting similar variations in the total yield, recorded earlier.

Contrary to seed size, all plantings and all spacings profited to the same extent in 'ware' from delay in lifting, and consequently in the yield. The seed fraction was not influenced by lifting time.

<u>FINANCIAL RETURNS.</u>

The differences in the price of the different grades 'ware', 'seed' and 'chats' render the consideration of the influence of the different cultural conditions on the total or the net yield of limited value. There is always a margin between the rates for 'ware' and 'seed' produced, in a relatively disease-free area. This margin, however, fluctuates widely from year to year, month to month, place to place and according to the quality of the seed,

To get a comparative idea, the crop values of each plot were computed at the following rates, prevailing in October, 1946 for the variety Gladstone, and statistically analysed:-

seed	157	shillings per	ton	(grade A)
ware	112/8	"	"	"
chats	40/	"	"	"

The/

Table XXX1. Financial Returns under different conditions (£ per acre)

Dates and spacing

	8 in	16 in	24 in
d_1	101.2	95.2	83.4
d_2	93.9	92.6	83.4
d_3	78.2	75.0	73.6

Dates and seed size

	s	m	l	mean (±1.442)
d_1	92.5	92.9	94.3	93.2
d_2	88.0	90.6	91.3	90.0
d_3	72.3	77.4	77.1	75.6

Spacing and seed size

	8 in	16 in	24 in
s	92.6	83.5	76.8
m	93.4	86.3	81.3
l	87.3	93.1	82.3
mean (±1.442)	91.1	87.6	80.1

Seed size and lifting time

	s	m	l	mean (±1.239)
t_2	87.3	89.1	89.0	88.4
t_1	81.3	85.0	86.1	84.1
Diff.	6.0	4.1	2.9	
mean (±.816)	84.3	87.0	87.6	

S.E. of the body of 3 x 3 sub-tables
dates and spacing.......................... ±2.497

Seed size.............................. ±1.414

Interaction T.S's (linear).... = 1.55 ±0.931

The contribution of the seed fraction to the aggregate crop value, was calculated on 'net seed' (Total seed <u>minus</u> seed used at planting) so that the different treatments may be comparable. This assumes that the seed was purchased at the same price as the sale price of the produce of new seed.

It may be stated that the price of Stock seed is not fixed and thus actually the magnitude of profits may be more than the present results would suggest, under certain conditions conducive to seed production. But in making safe generalizations, a smaller margin between 'ware' and 'seed' prices is to be preferred.

The Analysis of Variance is given in Table XXI and the summarised results in Tables XXXI.

Early planting and close spacing, singly and in combination, were the most remunerative. The increase in seed size added to the profits in a small measure only. Moreover, it did not enhance the effectiveness of early planting.

The relationship between seed size and spacing was the most interesting. Maximum returns were given by large seed with normal spacing (16") or by small or medium seed in combination with close spacing (8"). It has already been mentioned that close spacing and large seed when together represent conditions of acute competition and are thus incapacitated to give a full play to their potentialities.

1947

DESCRIPTION OF EXPERIMENTS.

The results reported in the preceding pages suggested that late planting was a victim of unbalanced development. The vegetative phase compensated at the expense of the storage so that the disadvantage of reduced 'time' factor showed up in the yield of tubers. The yield fell off steeply in case of the delayed planting, under manured conditions. In some seasons and in some localities, plantings have to be, perforce, postponed. It is, therefore, of fundamental importance to establish the most economic manurial policy under the circumstances.

It was surmised, on the basis of the growth behaviour of the potato plant, that late planting might not respond well to the nutrients which overstimulate the vegetative vigour e.g. nitrogen. On the other hand, it was possible that the performance of late planting could be improved by a plentiful supply of potash or by dung. Potash is the assimilator of new material, and is expected to replace sunshine and to restore the carbohydrate/nitrogen ratio, disturbed by the excess of nitrogen (Russel, 1937). This suggested the inclusion of the combinations of nitrogen and potash along with the cultural factors in the 1947 experiment. Such a study would also reveal the extent to which the different seed sizes and spacings would favour the utilization of the various nutrients.

A/

A piece of land covering about ~~1½~~ two acres, measuring 243' x 388' was selected in the Hay Knowes field at the Boghall Experimental Farm. It was not a perfectly level piece of ground but the variations in slope were regular in character. The area selected had a high centre and sloped downward regularly to the East as well as the West. Correspondingly, as revealed by a general survey and later confirmed by the mechanical analysis of the soil, the low lying places had comparatively heavier texture and the high ground was more sandy. The field was more or less even in the other direction, though it tended to be lighter South --→North.

The phosphoric acid content of the soil was reported to be medium and the pH ranged 5.7 - 6.4. The potash content of the soil as determined by the Aspergillus niger method was medium to low.

The previous crop on the field was Oats which was undersown with rye-grass and clover, in alternate strips running North - South transversely across the slope, and folded to sheep. The field was dressed with dung @ 15 tons per acre in the previous autumn and ploughed in winter. The extended winter and late spring did not permit any preparatory tillage till the 17th April. Due to the action of snow, however, three harrowings and a cultivation brought the field in perfect tilth for drawing ridges on the 19th April.

The area was divided up into four equal divisions by simultaneous double splitting (halving the/

the length as well as the breadth). One division was set apart for the collection of periodic observational data, on the selected treatments, and the remaining three reserved for the main experiment for the yield and the grades of produce.

Main Experiment: This experiment sought to study the interrelations of five factors. Nitrogen and potash were introduced as new factors, in addition to planting time, spacing and seed size of the previous season. All the five factors were designed to be at three levels but the non-availability of potassium sulphate restricted the choice of potash to only two levels (control, muriate of potash).

The actual specifications of the levels of cultural factors were slightly altered as compared with the previous year. 24" spacing was replaced by 12" and the seed sizes were adjusted to approximate more closely to 1,2,4 oz/per tuber. The interval between planting dates was reduced to 14 days, due to late spring.

The treatments were thus all conbinations of:

Factors	Planting date	Inter-set spacing	Seed Size	Nitrogen	Potash
(Symbols)	D	Sp.	Ss.	N.	K.
Levels	d_1 = 7/5/47	8"	s = $1\frac{1}{4}$"x$1\frac{3}{8}$"	n_o	k_o
	d_2 = 21/5/47	12"	m = $1\frac{1}{8}$"x$1\frac{3}{4}$"	n_1	k_1
	d_3 = 4/6/47	16"	l = 2"x$2\frac{1}{4}$"	n_2	

n_o = no nitrogen, n_1 = $2\frac{1}{2}$ cwt. Sulph. of Amm. p.a.
n_2 = 5 cwt. Sulph. of Amm. p.a.
k_o = no potash, k_1 = muriate of potash @ 2 cwt. per acre.
with a basal dressing of 5 cwt. superphosphate
(18% P_2O_5) to the entire area.

A/

A single replication of all combinations required $3^4 \times 2 = 162$ subplots. Provision of more replicates of an experiment of this size was neither feasible nor absolutely necessary, as the hidden replication property of the factorial experiment could be safely exploited to get an estimate of experimental errors (Fisher, 1935). Considerations similar to those for the 1946 experiment governed the choice of a 'confounded' split-plot arrangement (Fig. 6).

The three divisions, out of the four referred to above, furnished three blocks of nine mainplots each, for the 3 x 3 x 3 formation of the three cultural factors, thus confounding the 2 degrees of freedom with the fertility differences of the three blocks. Each mainplot (measuring 13½' x 164') was split across for three levels of nitrogen. The distribution of the three levels of N to the plots was random, with the restriction that some of the second-order interactions of N with the mainplot treatments were confounded with the transverse sub-blocks formed within main blocks. Each of the 81 N-plots was subdivided transversely for allocation of two potash levels strictly at random. The sub-plot at planting measured 13½' x 24' (6-drill width) and 4' wide buffer strips ran at all the cross divisions, to prevent the movement of manures. For cultural operations the mainplots were 164 ft. long, and 20 ft. wide unplanted rigs were provided at appropriate places (i.e. at either end of a mainplot).

The/

Fig. 6. Sketch plan of the $3^4 \times 2$ factorial experiments on potatoes at the Boghall Experimental Farm 1947

N

Main Block I

d_2 12" s	21	20	11	10	00	01
d_1 12" m	01	00	20	21	11	10
d_1 16" s	10	11	01	00	21	20
d_3 16" m	20	21	10	11	00	01
d_2 16" l	00	01	21	20	11	10
d_2 8" m	11	10	00	01	21	20
d_1 8" l	20	21	10	11	00	01
d_3 12" l	10	11	01	00	20	21
d_3 8" s	01	00	20	21	11	10

Six drills for expt. on cut seed. p.122

48 drills each 164' long used for growth observations on 16 treatments p.63

Main Block III

00	01	11	10	21	20	d_1 12" l
11	10	20	21	01	00	d_2 8" l
00	01	11	10	20	21	d_3 8" m
10	11	20	21	00	01	d_1 16" m
11	10	21	20	01	00	d_3 12" s
20	21	01	00	10	11	d_1 8" s
21	20	01	00	11	10	d_2 12" m
01	00	10	11	20	21	d_2 16" s
20	21	01	00	11	10	d_3 16" l

20	21	01	00	10	11	d_2 8" s
11	10	21	20	01	00	d_3 8" l
01	00	10	11	20	21	d_3 16" s
00	01	10	11	21	20	d_1 8" m
10	11	20	21	01	00	d_2 16" m
21	20	01	00	10	11	d_1 16" l
01	00	10	11	20	21	d_2 12" l
20	21	01	00	11	10	d_3 12" m
11	10	21	20	00	01	d_1 12" s

164' 20' 164'

Main Block II

Main Experiment:

d_1, d_2, d_3, denote successive planting dates
8", 12", 16" " spacings in inches
s, m, l, " small, medium & large seed
00, 01, 10, 11, 20, 21... denote n_0k_0, n_0k_1, n_1k_0, n_1k_1, n_2k_0, n_2k_1 being combinations of :-
three levels of notrogen (semi-main plot treatment)
two levels of potash (sub-plot treatment)

The direction of rows was East - West.

The area was laid out, on 21-24 April and hoe marks were made to demarcate the plots. Each planting was preceded by the collection of soil samples, a few days in advance, and by the application of the 6 manurial mixtures according to the sketch plan, on the day before planting. To ensure even distribution, the manures were sown by hand at the bottom of the drills, from paper bags, each containing a weighed dose per two-rows, 24' long. For convenience, the manures were weighed into small paper bags one day before sowing in the case of each planting.

The selection of seed and the use of strings marked at specific distances (8", 12", 16") followed the usual procedure outlined for the 1946 experiment. The variety used was again Gladstone stock seed grown at the Boghall farm. The dates of cultural operations are given in Table XXXII.

The final yield from each subplot was recorded in the usual commercial grades, ware, seed and chats. A measure of the potash status of each subplot was determined by analysing soil samples, taken earlier, by the Aspergillus niger method.

Of the 162 subplots, 60 were analysed for the determination of coarse and fine sand in proportion to the lighter fractions. The 60 soil samples were so chosen that the values of the rest could be interpolated with a fair measure of reliability, if the data suggested a linear trend. The aim was to look for internal evidence in the data for the relationship/

Table XXX11. Dates of cultural operations (1947 Experiment)

Preliminary tillage............. 17-18/4/47
(3 harrowings and 1 cultivation)

Ridging or drilling............ 19/4/47

Layout......................... 21-24/4/47 $\underline{d}_2$ and $\underline{d}_3$ plots harrowed down and re-ridged a couple of days before the respective planting dates, to keep down weeds.

Planting.....	7/5/47 ($\underline{d}_1$)	21/5/47 ($\underline{d}_2$)	4/6/47 ($\underline{d}_3$)
Harrowing and cultivating.	30/5/47	30/5/47	
Bulking up...	2-3/6/47	2-3/6/47	
Harrowing down........	7/6/47	7/6/47	7/6/47
Grubbing....	16/6/47	16/6/47	16/6/47
"	3/7/47	3/7/47	3/7/47
Hand hoeing..	9/7/47	9/7/47	9/7/47

Final ridging	$\underline{d}_1$ l, $\underline{d}_1$ m, $\underline{d}_2$ l 11/7/47	)An attempt was)made to ridge up)the plants at)corresponding)stages of plant development.
	$\underline{d}_1$ s, $\underline{d}_2$ m, $\underline{d}_3$ l 18/7/47	
	$\underline{d}_3$ m, $\underline{d}_2$ s, $\underline{d}_3$ s 26/7/47	

Lifting............................13-14/10/47

Grading and weighing...............14-16/10/47 relationship between fertilizer response and the physical properties of the soil which seemed to vary in a systematic manner within the area. It was also designed to make allowance of variations in the texture of the soil and improve the accuracy of some of the comparisons by 'Covariance' (Sanders, 1930) although this attempt was not successful. ($r = +.24$ for $n=14$)

Description of the observation plots.

The comprehensive $3^4 \times 2$ experiment sought to provide information from an agronomic stand-point. Clearly, to take extensive observations on each plot of an experiment of this type, though highly useful, required large resources. It was, however, possible to supplement yield studies by growth records on a limited set of treatments and utilize the information emanating from them for growth analysis and for explaining the behaviour of different treatments on the final yield collected from the main experiment.

48 drills in the fourth division of the area selected were utilized for this purpose. (Fig.6). The treatments chosen for this study were all combinations of:

Planting dates	Seed Size per tuber	Nitrogen	Potash
D	Ss	N	K
(d_1 =8-5-47	(s = 1oz.)	(n_0 =No nitrogen)	(k_0=No potash
d_{3} = 4/5-6-47	(1 = 4oz.)	(n_2 = 5 cwt. S/A) p.a.	(k_1 = 2 cwt. muriate) of potash p.a.)

in two blocks of 8 plots each, confounding D x Ss. x N x K interaction.

Thus/

Thus the central level of each of the four factors enumerated above was omitted here, and the Spacing factor was not included. All the plots were planted at 16" spacing between sets and 27" between drills. Each plot consisted of 3 drills, 164' long, running the entire block length. The central row of each plot served as the experimental row for observational purposes. The provision of border rows obviated interference to the central rows during sampling and collection of other records. They were also otherwise necessary in an experiment of this type where treatments with varying growth are growing side by side.

The seed for the central (experimental) row was specially prepared. A different procedure was adopted this year for reducing the variability of the planting material. Eight plots had to be planted each time. Four of these were to be planted with small seed and four with large. The length of the row being 164 ft. about 500 tubers of each size were required for each planting. The required numbers were therefore washed thoroughly, and weighed individually, when air dry, to one place of decimals in grams. The weight of the individual tuber was recorded on the tuber itself with water-proof Indian ink. The tubers were then divided into as many lots as there were plots to be planted, so that all plots under a particular seed size were receiving similar planting material. Each plot lot was further graded into/

into 5 classes, on the basis of the recorded weight, and these planted up the row in 5 sections, in an ascending order. At sampling, one member per section of a row was removed at random to give a composite sample of 5 per row (per plot or treatment in the present case) at each occasion. As each section was to be equally represented in a composite plot-sample, the variations due to seed or to soil between the sections did not influence the accuracy of the plot samples. Besides, the inequalities of seed size within the sections influencing the plot samples could, if required, be taken account of later, on the basis of seed weights, ineffaceably recorded on the tubers.

The chief aim of knowing the weight of the planting material with accuracy was to evaluate the rates of depletion of food material from the mother tuber, at successive stages of sampling.

The growth data were recorded according to the scheme in Table XXXIII.

"STATISTICAL ANALYSIS"

As in 1946, the experiments conducted during 1947 satisfied the necessary theoretical requirements (i.e. randomness, local control, and replication - absolute or hidden) of well-designed experiments to the results of which Fisher's 'Analysis of Variance' and 'tests of significance' could be legitimately applied. Both the main experiment and the observational experiment of 1947 differed from the experiments of the preceding year in that no absolute replication was provided/

Table XXXIII. Collection of Data.

Observation	Dates of observation d_1 1st	d_1 last	d_3 1st	d_3 last	Sample (Plants per plot)	Observation Interval in days in general	
Emergence	9/6	23/6	22/6	10/7	Whole plot	1	
Nodes	23/6	18/8	21/7	25/8	5	7	same plants
†Height	14/7	18/8	21/7	25/8	5	7	same plants
Flowering shoots	28/7	9/8	3/8	18/8	5	2	same plants
Sprouts	25-26/6	4- 5/9	23-24/6	2- 3/9	5	14	sampled plants.
‡Mother tubers' Fresh & dry wt. and sugars.	29-30/5	10-11/7	23-24/6	22-23/7	5	"	sampled plants.
Dry wt. (all parts)	29-30/5	21-22/8	23-24/6	2- 3/9	5	"	sampled plants.
Fresh wt. (shoot)	10-11/7	21-22/8	8- 9/7	19-20/8	5	"	sampled plants.
⊙Tubers (No. & wts)	"	4- 5/9	22-23/7	2- 3/9	5	"	sampled plants.

†Excluding basal three internodes

‡Determinations also made on seed planted.

⊙Samples taken for fresh and dry wt. of tubers and their number at maturity also.

provided for in 1947. The estimate of error could, however, be obtained from the high-order interactions which could safely be assumed to be negligible in the light of 1946 results and the experience of other workers. Recognizing the intimate relationship between design and its analysis, there were three estimates of errors in the main (five-factor) experiment: (a) Error for planting time, seed size and spacing effects. (b) Error for Nitrogen and its worth-while interactions with the main-plot factors. (c) Error for potash effect and its worth while interactions with the remaining factors.

The analysis of variance of the main-plot part of the experiment which also involved 'confounding', followed essentially the standard procedure out-lined by Yates (1937, p. 53-55) whereby the main effects and the first-order interactions (Linear x Linear) could be compared against a pooled estimate of the remaining components (15 d.f.). For the ~~sub~~ semi-main-plot part of the analysis, it was necessary to realize that the restriction, imposed on complete randomisation of N to the plots, was allowed for in the analysis. The variation between sub-blocks was, therefore, to be eliminated from the estimate of the second error, which must be composed of the remaining second and third order interactions. The third error was simply calculated by deducting the sum of squares, corresponding to potash and all its first-order interactions, from that of the total within-plot (81 d.f.) sum of squares.

On/

On analogy, the error for the observational data could be evaluated from the triple-factor interactions (4 d.f.). To base error on large number of degrees of freedom some of the first-order interactions which proved unimportant on most growth characters could however be justifiably included in error. The use of 'Covariance' method for a stage to stage analysis of the developmental data, as demonstrated by Garner et al (1934), had limited possibilities in the present case, for obvious reasons.

The Method of Presentation of data.

In the presentation of results, the tables of the 'Analysis of variance' (Nos XXXIV, LV) are given collectively at appropriate places, as they serve to point the way to the preparation of summary tables in customary units or to the graphical representations.

The periodic data is largely graphically depicted. For this, a uniform procedure is adopted in that the effects of the factors N, K, and seed size with either of the two plantings can be followed up stage by stage, in case of the different developmental characters. The interactions of factors are given in tabular form. The relative growth rates, net assimilation rates and Leaf-weight ratios are illustrated by graphs. Finally, the yield data and the economic aspects are considered from two-way tables, and the statistical aspects of the designs of the two years (pp.123-125) are briefly disserted.

Table XXXIV A. Analyses of Variances (mean squares and their significance)

Due to	d.f.	Mean date of emergence	Height (21-7-47)	Height 4-8-47	Height final	Nodes final	Inter nodal length final	Flowering shoots final	Maximum dry wt. (excluding tubers)	†Dry matter per 100 gm. fresh wt. of haulms	²Leaf wt. ratio	‡Net assimilation rate
D.	1	xx 1046.52	xx 617.52	2.98	xx 337.64	.122	xx 1.0558	xx 18.92	x 7310	xx 23.8999	xx .003906	.6052
S.	1	xx 26.01	xx 545.22	xx 498.41	xx 126.00	xx 11.222	xx 1.5562	xx 45.56	xx 29584	1.3658	xx .047829	x 2.4255
N.	1	1.44	xx 390.06	xx 1534.68	xx 2206.65	xx 15.602	xx 4.0300	xx 27.56	xx 135056	x 5.7658	xx .137788	xx 3.3022
K.	1	.42	13.69	51.48	x 43.89	x 3.802	x .4258	.42	x 10609	xx 39.8476	x .001260	x 1.0830
D.S.	1	2.40	.20	24.75	.39	.002	.0138	x 3.42	2500	.0153	x .002916	.2626
D.N.	1	.02	111.30	86.03	17.85	.122	.0743	x 2.10	x 6006	.8532	.000156	.0196
D.K.	1	x 5.76	4.84	9.15	x 43.89	1.822	.0264	.72	784	.7546	.001005	.0698
S.N.	1	1.00	57.00	26.78	5.40	.902	.0011	x 5.52	361	.0337	.000408	.1376
S.K.	1	2.72	3.24	.23	.39	.002	.0003	1.32	380	.1064	x .002450	.0137
N.K.	1	.20	36.00	x 177.56	xx 373.46	.902	xx .8883	1.82	x 10404	.7853	.000961	.1599
Error.	4	0.3662	15.94	22.91	3.278	.337	.0246	0.248	595	.3359	.0001364	.1268
D.S.N.K. = block	1											

†4 stages pooled ‡3 stages (common to d_1 and d_3) pooled ²4 comparable stages pooled.

Table XXXIV B. Analyses of Variances (mean squares and their significance)

Due to	d.f.	Potential tuber number 3 stages	Size of potential tubers 2-5/9/47	Number of sizeable tubers 2-5/9/47	Tuber size (excluding chats) 2-5/9/47	Fresh wt tubers 2-5/9/47	Dry wt tuber 2-5/9/47	†Dry wt. per 200 gm fresh wt.
D.	1	1692	476.33^{xx}	156.25^{x}	315.06^{x}	11077^{xx}	122850^{xx}	292.41^{xx}
S.	1	18291^{xx}	52.92	870.25^{xx}	175.56^{x}	18428^{xx}	130682^{xx}	17.43^{x}
N.	1	1333	119.35	1.00	573.60^{xx}	9950^{x}	93636^{xx}	4.41
K.	1	38	22.80	182.25^{x}	.36	5365^{x}	12100	88.83^{xx}
D.S.	1	42	69.30	42.25	211.70^{x}	1139	12210	3.24
D.N.	1	123	136.30	100.00	17.22	5814^{x}	52441^{x}	.95
D.K.	1	728	1.38	0.25	4.84	1	4	1.69
S.N.	1	713	.52	25.00	18.92	689	4225	1.00
S.K.	1	130	24.25	56.25	.16	976	7396	.00
N.K.	1	117	46.58	169.00^{x}	231.04^{x}	27	210	.72
Error	4	239	21.38	15.81	19.08	505.3	3252	2.192
D.S.N.K. =block	1							

† 4 stages pooled

EXPERIMENTAL RESULTS.

Treatment effect on Plant Development.

Sprout emergence.

The daily counts of the progress of sprout emergence revealed the effect of seed size positively (Table XXXV). The seed size effect was better marked under the second planting where about 50% of hills planted with large seed were full, 3½ days earlier than those with small seed. The corresponding difference was 1½ days under the early planting. In general, the full stand was rapidly attained with the large seed. On the whole, the superiority of large seed was of a reduced order in 1947 as compared with the preceding year. The cause of this is not immediately clear but the weather conditions during the winter storage and the soil temperatures during sprout emergence had probably something to do with this. It is possible that milder winter and higher soil temperatures during germination widen the gap between the large and the small seed, in the matter of sprout establishment.

The two plantings were done at an interval of 27 days, but the mean difference in their emergence was 15½ days under large seed and 17 days under small seed. (Table XXXVI).

Nitrogen tended to accelerate sprout emergence but the trend fell short of a significant difference. The generalized effect of potash was non-significant but its differential behaviour with planting time precipitated out a spurious D x K interaction which has/

Table XXXV. Treatment effects on percentage stand.

(Early planting)

Dates→	9/6	10/6	11/6	12/6	13/6	15/6	16/6	18/6	19/6	20/6	21/6	22/6	23/6
d_1 s	3.0	12.7	27.0	34.9	42.3	68.7	71.7	87.0	91.7	93.3	96.0	96.8	97.0
d_1 l	14.0	29.5	44.6	51.1	62.6	83.5	86.9	93.3	96.0	97.1	97.8	97.9	98.2

(Late planting)

	22/6	23/6	24/6	26/6	27/6	28/6	29/6	30/6	1/7	2/7	3/7	4/7	5/7	6/7	7/7	8/7	9/7	10/7
d_3 s	-	-	-	3.2	12.6	24.7	35.6	47.4	55.9	64.1	71.2	74.0	77.6	84.7	87.1	88.8	90.0	91.9
d_3 l	3.4	9.5	12.9	23.2	49.1	68.8	78.2	86.2	91.0	94.4	95.5	96.5	97.6	98.5	98.7	98.7	99.0	99.5

Table XXXVI. Mean date of emergence.

50% stand completed on June

	d_1	d_3		d_1	d_3		n_0	n_2	S.E. (means)
s	13.5	30.5	o	13.4	28.4	o	21.1	20.7	
l	11.7	27.1	k	11.9	29.2	k	21.0	20.1	$\pm$ 0.302

has no physical meaning and hence is to be ignored.

The second planting commenced appearing above ground earlier than its planting date would suggest, but there was no evidence that it completed its stand more rapidly.

Sprout number: Counts taken on sampled plants six times during the season confirmed the conclusion already reached that seed size and the resulting sprouts were associated characters (Table XXXVII). Delay in planting also induced higher sprout production, more so in case of the large seed. Within limits, therefore, the effect of late planting was proportional to seed size.

There was little effect of nutrients on the establishment of sprouts. The influence of manures on crop yields recorded later should, therefore, be looked for in sources other than sprout number. Under natural conditions, the nutrient status of the soil will seldom be so low as to limit the sprout number. The establishment of sprouts was determined chiefly by factors localised inside the 'seed'.

The Depletion of Food Material from the mother tuber:

The mother tubers under different conditions, continued to lose dry matter progressively (partly through respiration and partly in nourishing the young sprouts) not only during the initial stages but when the sprouts were well up to help themselves. (Table XXXVIII). The dry matter percent declined from the initial value of 18% nearly to about 4% by the 10th July/

Table XXXVII. Treatment effects on sprout number

	Dates and seed size				Nitrogen and potash					
	Height plants		Sampled plants			Height plants			Sampled plants	
	d_1	d_3	d_1	d_3		n_0	n_2		n_0	n_2
s	3.45	3.85	3.57	4.02	k_0	6.55	6.55	k_0	6.52	6.74
l	8.05	10.95	8.01	10.40	k_1	6.05	7.15	k_1	6.40	6.32
S.E.	±.65		±.203			±.65			±.203	

Table XXXVIII. Depletion of food material from the mother tuber.

Percent dry matter at successive stages ($\frac{\text{Dry wt.}}{\text{Fresh wt.}} \times 100$)

	d_1				d_3			
	29/5	12/6	25/6	10/7	27/5	23/6	8/7	22/7
n_0	17.3	15.0	6.9	3.9	18.1	16.1	8.4	3.7
n_2	17.9	15.4	7.7	4.3		15.1	8.4	3.9
k_0	17.8	14.9	6.8	3.9	18.1	15.0	8.2	3.5
k_1	17.4	15.5	7.8	4.3		16.3	8.5	4.1
s	17.2	14.9	6.8	4.0	17.9	14.9	8.8	3.8
l	17.9	15.5	7.8	4.2	18.2	16.4	8.0	3.8
mean	17.6	15.2	7.3	4.1	18.1	15.7	8.4	3.8

10th July in the first planting and about a fortnight later in the second planting, in conformity with a similar difference between the plantings in sprout emergence.

The rate of fall was not materially influenced by any of the nutritional factors. Taking the two plantings together, there was no consistent response to N on the percentage of dry matter. Potash tended to inhibit depletion during the post-germination phase. The effect of seed size under the first planting pointed in the same direction as the 1946 results; but under the late planting, similar tendency was noted in the early stages only.

It may be noted that the initial dry matter content (18%) in May was lower by 5 - 6% as compared with the initial dry matter in April in the preceding year. This may be attributed to two sources (1) The moisture content of the tubers from the 1946 crop was high due to its wet summer (2) The thick cover of snow through the winter and low temperatures during the storage period reduced water losses. All the same in 1947, as in 1946, the mother tubers began to increase in fresh weight after going into the ground (Table XXXIX). Till the sprouts had thrown out roots, however, the fresh weight of the mother tubers dropped, whether the tubers were lying exposed outside or they were in the ground. As soon as the sprouts were established, the sprouts and the mother tuber were in a state of mutual dependence, the former/

former supplying it with water and the latter nourishing them from below. Apparently, the concentration of sugars and other soluble substances was high enough to exercise osmotic pressure of a magnitude to maintain the mother tuber in a turgid and firm condition.

The gain in the fresh weight of the mother tuber after planting was of the same order in the two seed sizes as well as at the two levels of potash. The case with nitrogen was different. The fresh weight did not rise as high in the presence of nitrogen as it did in its absence. This may be understood in terms of the internal competition for water. The relative abundance of proteinaceous substances and the actively expanding cells of the vegetative organs under nitrogen application make heavier demands for water and therefore restrict the increase in the fresh weight of the mother tuber. In the absence of nitrogen, the fresh weight rose by 10-14%, in conformity with the results of the previous year.

<u>Changes in the absolute dry matter of the mother tuber:</u> The individual plot values for the dry matter of the mother tubers at the successive stages were adjusted for inequalities in seed from the respective mean seed weights, viz., 30 gm. per tuber in the case of small seed and 127.5gm. per tuber in the case of large seed. For ease of computation, the internal evidence emanating from the mean variation caused by the seed size factor at each stage, on the total dry matter, was utilized for this adjustment.

The/

The absolute dry matter declined continually throughout, but the fall was distinctly more rapid with large seed (Table XL). The effect of nitrogen, despite its large influence on top growth recorded later, caused very little differences in depletion. Potash did not stimulate the mobilization of food from the mother tuber.

Though the fresh weights chosen for this study compared well with corresponding values for 1946, the dry matter per tuber was lower, as stated earlier. As the plantings were late in 1947, nearly 75% of the food material depleted towards the middle of July, synchronizing in time with the depletion in 1946. Consequently, the fortnightly interval was rather wide for a fuller study of the progressive changes. It is however, worthy of note that the depletion was slow at first, rose rapidly to a maximum and then declined. (Table XLI). The depletion rates thus follow the same plan, which the resulting plant follows (cf. Sach's grand period of growth). The greatest depletion synchronized with the period of leaf expansion, following the emergence of sprouts from the ground. It is to be expected that a lot of carbohydrates are used up during this period in respiration and laying down new primordia. This need is met from the mother tuber till the plant can support itself. The photosynthetic apparatus is in the formative stage, and the young leaves already formed are not photosynthesising at their maximum rate (see p.100)

and/

and also Briggs et al (1920), Briggs (1920), IRVING (1910)..) If the mother tuber were incapable of making a substantial contribution to the young sprout after emergence, the sprout may still hold on, but the growth will be very restricted over a considerable length of time. The capacity of the mother tuber to nourish the sprout even after emergence, therefore, makes for earliness. The slow development of the potato seedlings and the effect of seed size on development, are evidence in this direction.

It is evident that a greater amount of food material was passing into the plant from the large seed as compared with the small. Since the number of sprouts was slightly more than doubled when the seed size was quadrupled, the individual sprouts from the large seed were better fed and they therefore had better chances for establishment and early development.

The phase of maximum depletion was characterised by slightly higher depletion rates under nitrogen. ~~The converse seemed to hold true of potash.~~

<u>The Relative rates of depletion:</u> The relative rates of depletion were not influenced widely and regularly by changes of conditions. About 83-85% of the total dry matter was still present in the mother tuber when the sprouts were on the verge of emergence, irrespective of the seed size. (Table XLII). The corresponding values were 86-90% in 1946. These figures were reduced to about 50% during the leaf expansion phase.

Depletion/

Table XXXIX. Fresh weight expressed as percentage of the original Fresh weight.

		29/5	12/6	25/6	10/7	27/5	23/6	8/7	22/7
		(First Planting).					(Last Planting)		
n_0	96.8	98.4	111.5	111.7	112.3	97.7	105.5	114.3	110.0
n_2		97.4	108.9	108.9	104.4		105.9	107.8	103.7
k_0	96.8	98.2	110.3	110.1	107.8	97.7	106.7	111.6	106.9
k_1		97.6	110.1	110.4	108.9		104.8	110.5	106.8
s	96.2	98.3	110.9	109.4	108.0	97.4	106.0	111.7	107.6
l	97.4	97.5	109.5	111.2	108.8	98.0	105.5	110.4	106.1

TableXL. Progressive changes in the absolute dry matter (g) of the mother tuber.

	First Planting				Last Planting			
Treatment	29/5	12/6	25/6	10/7	27/5	23/6	8/7	22/7
n_0	13.26	11.74	7.41	3.63	13.83	13.80	8.25	3.41
n_2	13.86	11.65	6.89	3.79		13.40	6.93	3.13
k_0	13.78	11.48	6.79	3.40	13.83	13.33	7.75	2.96
k_1	13.35	11.92	7.50	4.0		13.87	7.43	3.58
s	5.21	4.48	2.44	1.35	5.40	5.03	3.30	1.31
l	21.92	18.91	11.85	6.07	22.25	22.17	11.88	5.24

Table XLI. Absolute rates of depletion of dry matter from the mother tuber.

Treatments	29/5 to 12/6	12/6 to 25/6	25/6 to 10/7	27/5 to 23/6	23/6 to 8/7	8/7 to 22/7
	(First planting)			(Last planting)		
$\underline{n}_0$	1.52	4.33	3.78	.03	5.55	4.84
$\underline{n}_2$	2.21	4.76	3.10	.43	6.47	3.80
$\underline{k}_0$	2.30	4.69	3.39	.50	5.58	4.79
$\underline{k}_1$	1.43	4.42	3.50	-.04	6.44	3.85
$\underline{s}$	1.73	2.04	1.09	.37	1.73	1.99
$\underline{l}$	3.01	7.06	5.78	.08	10.29	6.64

Table XLII. Dry matter content of the mother tuber at successive stages, expressed as percentage of that at the beginning.

	Early planting				Late planting			
	29/5	12/6	25/6	10/7	27/5	23/6	8/7	22/7
$\underline{n}_0$	95.9	84.9	53.6	26.3	100	99.8	59.6	24.7
$\underline{n}_2$	100.2	84.2	49.8	27.4		96.9	50.1	22.6
$\underline{k}_0$	99.6	83.0	49.1	24.6	100	96.4	56.0	21.4
$\underline{k}_1$	96.5	86.2	54.2	28.9		100.3	53.7	25.9
$\underline{s}$	96.5	83.0	45.2	25.0	100	93.2	61.1	24.3
$\underline{l}$	98.5	85.0	53.3	27.3		99.6	53.4	23.6

Depletion continued till it fell to about 25% of the original, all over. The slightly lower relative depletion <u>rates</u> in the large seed recorded in the first planting as well as in 1946, were not borne out under the late planting. This may be interpreted in terms of the differences in the sprout number which were specially high in d 1.
3

<u>The concentration of sugars:</u> The concentration of sugars (total) showed similar trends with time as in 1946. From a value of about 1% of fresh weight in the preplanting period they tended to decrease during emergence, (Table XLIII). During the period of leaf expansion characterised by high losses of the dry matter of the mother tuber, there was a phenomenal increase in the sugar concentration all over. This was followed by a gradual decrease. In the large seed, as high as 2% of sugars were recorded. The depletion of food material from the mother tuber was therefore directly related to the concentration of sugars. It may, however, be argued that sugar concentration should have decreased if the depletion was proceeding at a rapid rate. Denny (1929) expressed surprise over the rise in sugar concentration when the plant is well grown and is capable of photosynthesising. Whatever the explanation, increase in sugar in the mother tuber, after the emergence of sprouts, is a fact, and its practical consequence is the acceleration of the plant development. There are/

Table XLIII. Concentration of total sugars in the mother tuber (expressed as reducing sugars per 100 g fresh material.)

	Early planting					Late planting			
	1/5	29/5	12/6	25/6	10/7	27/5	23/6	8/7	22/7
n_0	1.02	.76	.99	1.97	1.55	1.01	1.05	1.86	1.21
n_2		.92	.97	1.97	1.53		1.02	1.84	1.04
k_0	1.02	.83	.97	2.07	1.54	1.01	1.05	1.85	1.06
k_1		.85	.98	1.88	1.53		1.02	1.84	1.19
s	1.06	.83	1.00	1.79	1.30	1.03	1.04	1.68	.87
l	.99	.85	.95	2.15	1.77	.98	1.03	2.02	1.37

Table XLIV. Interaction : Nitrogen and potash

	Height (cm)						Internodal length					
	21/7		4/8		Final		21/7		4/8		Final	
	n_0	n_2	n_0	n_2	n_0	n_2	n_0	n_2	n_0	n_2	n_0	n_2
k_0	22.1	29.0	37.6	50.4	46.8	60.7	2.01	2.41	2.51	3.02	2.79	3.33
k_1	20.9	33.8	34.6	60.8	40.5	73.6	1.91	2.94	2.47	3.80	2.65	4.12
				x	xx	xx		x		xx		xx
diff	-1.2	4.8	-3.0	10.4	-6.3	12.9	-.10	0.53	-.04	0.78	-0.14	0.79
$S.E._d$	±2.82		±3.39		±1.28		±.192		±.153		±.111	

Table XLV. Rate of leaf production in relation to mean maximum and minimum temperature (°F)

	June	July					August	
	23-30	30-7	7-14	14-21	21-28	28-4	4-11	11-18
n_0	1.5	3.5	1.9	1.7	1.5	2.0	0.2	0.2
n_2	1.8	3.5	2.5	1.4	2.4	2.1	0.4	0.4
s	1.8	3.3	2.2	2.0	2.2	2.2	0.3	0.6
l	1.5	3.8	2.2	1.1	1.7	1.9	0.2	0.1
k_0	1.8	3.5	2.5	1.8	2.1	2.3	0.2	.4
k_1	1.6	3.5	1.9	1.3	1.9	1.7	0.3	.3
Mean temper-ature (°F)	59.4	55.6	56.4	61.6	58.9	61.2	59.0	63.4

are two possibilities :(1) Either the mother tuber is supplied with the necessary enzymes by the new plant and these catalyse the reaction (2) or the higher concentration of sugars are restricted to a particular time of the day. A study of the diurnal changes of the sugars alone can clarify the issue. A detailed investigation on the diurnal changes could not be undertaken on account of the rush of other work, but on 22nd July, duplicate samples were taken in the morning and again in the evening (5.p.m.). The afternoon samples gave o.77 and o.99% of sugars corresponding to 1.20 and 1.54% sugars in the morning samples respectively. It appeared therefore that the starch manufactured in the leaves and stored there during the hours of sunshine was hydrolyzed and translocated at night for utilization in growth and thus less demands were made on the mother tuber which released more sugars, through diastatic activity, than the rate of removal at certain periods. During hours of daylight, however, the mother tubers played a greater part in feeding the plants, and consequently the sugars had lower values in the afternoons. The data are, however, inadequate to make an emphatic statement on the subject.

It may be noted that at all the stages after sprouting the sugar concentration was lower in the small seed as compared with the large. In 1946, on one of the occasions after emergence, the sugar concentration in the small seed exceeded that in the large. With fortnightly intervals of sampling, all

all the changes in sugar concentration with time cannot be recorded.

The nutritional factors did not influence the concentration of sugars in the mother tuber. This is particularly interesting in case of nitrogen which produced a large effect on the growth of the plant, as shown later, without exercising any indirect effect on the mother tuber.

The mother tubers of the late crop had lower sugars, as compared with the early, at corresponding stages of plant development.

The effects of Nitrogen, Potassium, seed size and planting time on growth.

General observations: The effects of nitrogen and potash could be detected on the foliage by the time 95% of the stand was completed. N - plots were distinctly darker and the K - plots lighter than the corresponding controls. These differences were recorded relatively earlier on the plants arising from the large seed. The colour differences widened for a time between the manured and unmanured plots and with the gradations introduced by other factors (planting time; seed size) the whole piece presented an impressive patch-work appearance. (This was particularly true of the main experiment where the 162 plots were treated differently). Towards flowering; and later, although the effect of N was well marked on colour and growth in the absence of potash, its effect in the presence of potash on colour began to be/

be masked. The two nutrients apparently were reinforcing each other on growth. There were no abnormal potash deficiency symptoms on plants which did not receive muriate of potash. It was noted that N - treated plants exhibited drooping of leaves towards the end of August. The plants which received both nitrogen and the muriate of potash appeared to suffer much less in comparison. In the absence of N, muriate of potash exhibited characteristic upward curling of leaves, in portions where the soil was heavy.

The late planted crop appeared to be softer and fresher than the early throughout growth.

Plants from large seed appeared to pale off earlier and suffer from early senescence and drought.

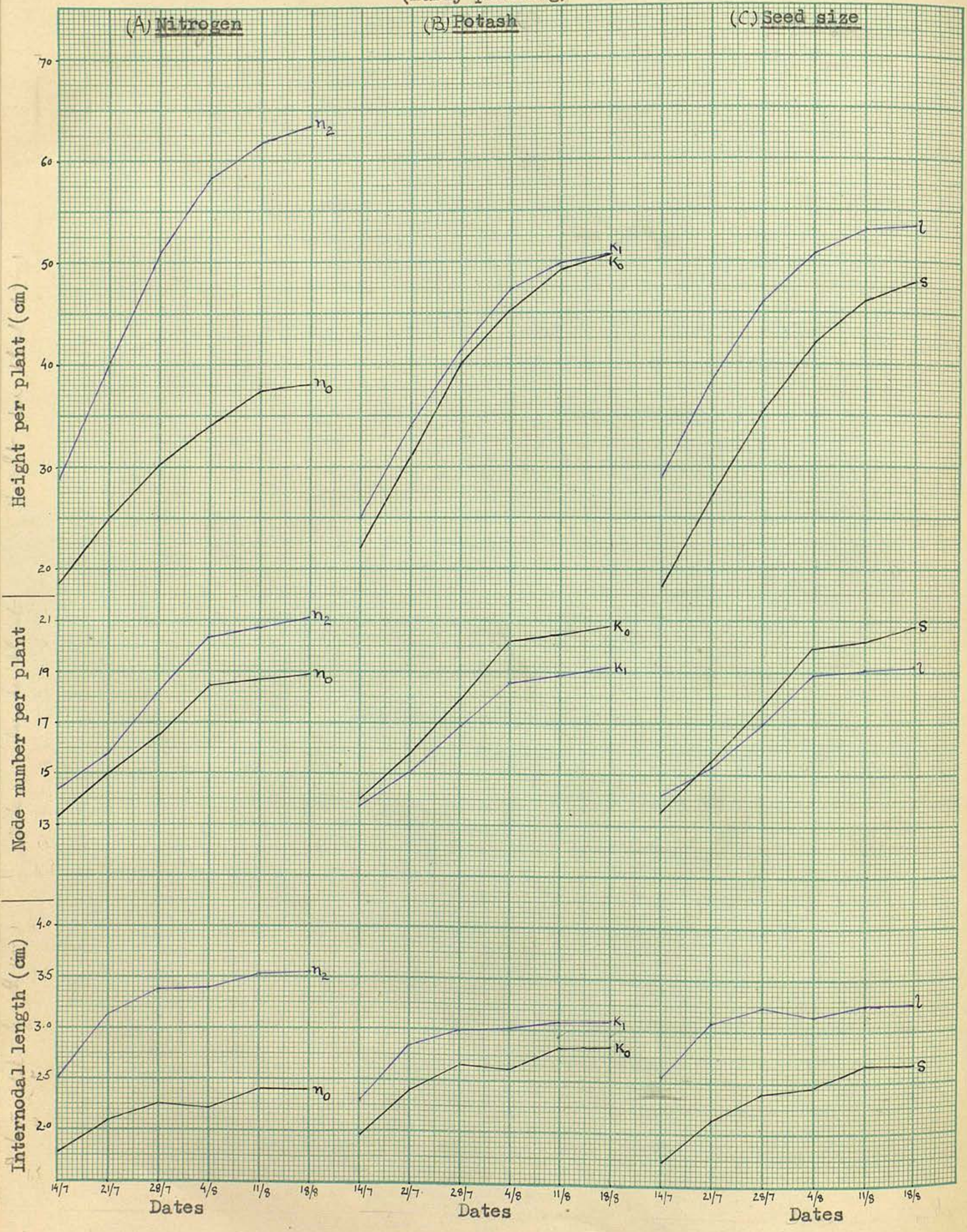
The wilting of leaves on account of prolonged drought was more pronounced on the heavy soil. The 'chlorine' ion in the 'muriate' seemed to exercise a 'bleaching' effect not only on the vegetative parts but on the tubers also. The pink colour of the Gladstone tubers was localised about the eyes only, where the muriate was applied. The pulp too was lighter in appearance and changed colour (tyrosinase activity) rather slowly on exposure.

<u>Height, node number and the length of internodes.</u>

<u>Nitrogen</u> - The effect of nitrogen on the length of internodes was antecedent to that on node-production (Figs. 7.8). The influence of nitrogen on height as early as the 21st. July in d_3 was almost wholly contributed by the 'extension growth'. This is understandable/

Fig 7. TREATMENT EFFECTS ON HEIGHT, NODE NUMBER AND INTERNODAL LENGTH

(Early planting)



Understandable for the extra nitrogen absorbed under artificial application exercises its immediate influence through the expansion of the internodes already laid down (provided of course water supply is not limiting). The effect of nitrogen on the production of more nodes (leaves) came on slowly but their contribution towards increase in height was much smaller as compared with that of the elongation of internodes.

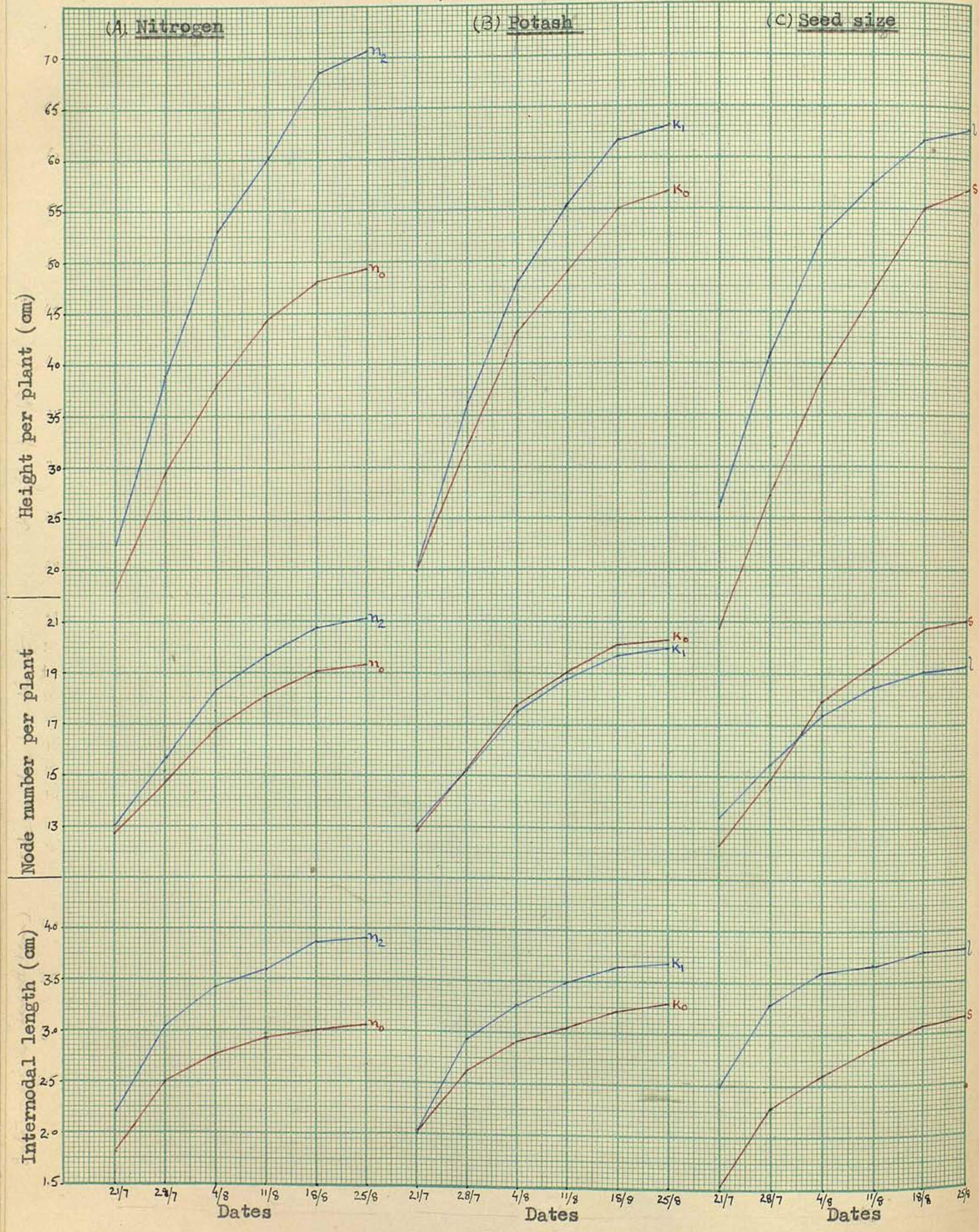
It is interesting to note that, both with and without nitrogen, the mean internodal length steadied down earlier than the node production. As internodal length is directly or indirectly a function of water, this connotes internal competition for water when the plants are well grown.

The effect of nitrogen on height was very high in either of the two plantings.

<u>Potash:</u> The muriate of potash depressed leaf production in the early planting but not in the late. (Figs. 7, 8, ~~13~~ B). The cause of this differential behaviour is not certain, but it is positive that meristematic activity was not controlled by potassium. Verma (1935) arrived at the same conclusion from the data for tillering of the barley plant under different nutrients. The effect of the muriate on the expansion of internodes was consistently brought out at all stages and under either of the two plantings. The positive effect of the muriate on the internodal length reflected differences in height under late planting; but, under the early planting, the positive effect/

Fig. 8. TREATMENT EFFECTS ON HEIGHT, NODE NUMBER AND INTERNODAL LENGTH

(Late planting)



effect on the internodal length was cancelled by a negative effect on node number so that height was not influenced by this factor. D x K interaction was suggestive ~~significant~~ on node number and consequently on height.

Seed size: Leaf number tended to be higher in the plants from large seed in the earlier stages, linked no doubt with their early emergence, but really marked differences between the plants of the two seed sizes developed spasmodically in the length of their internodes (Fig 7,8 C). In 1947, as in the preceding season, the sprouts from the small seed commenced putting forth new leaves (nodes) at an accelerated rate and eventually produced more leaves per sprout than those from the large seed. Similarly, the former tended to catch up the latter, in regard to the elongation of the internodes, but they failed to do so, on account of the comparatively dry summer which forced the plants to mature earlier. The seed size influence, therefore, persisted in height, irrespective of the time of planting. Its reaction on yield will be discussed later.

Planting date: The height of the sprouts of the late planting equalled that of the early by the end of July, in the absence of nitrogen. This was caused by longer internodes in the former for the number of nodes - largely a function of time - were still far below the early one (cf. Figs. 7A & 8A). In course of time, the late planting made up in node production and produced still longer internodes and consequently excelled/

excelled the early in height. A study of the differences in the slopes of the curves under the early and the late planting clearly show the higher rates of leaf production as well as the elongation of the internodes, in the late planting, both in the presence and the absence of nitrogen. The effect of planting time is in complete agreement with the finding of the previous year, despite wide variations in the climatic conditions of the two seasons. The increased number of sprouts in the late planting may be suggested as a partial explanation, but the real cause is elsewhere.

Interaction : nitrogen and potash - The interdependence of the two factors was well demonstrated on height as well as the length of internodes (Table XLIV). Potash was inneffective in the absence of nitrogen but its effect was positive in the presence of nitrogen and developed with time. In other words, the response to nitrogen was greatly enhanced in the presence of potash.

The rate of leaf production: The weekly nodal counts at the successive stages on the same plants, permitted a calculation of the rates of leaf production with time, under different conditions (Table XLV). It is note-worthy that the rate had maximal values in the first week of July, after which rate declined to about 1.5 - 2 nodes per week till the first week of August. Thenceforth, node production slowed down presumably under pressure of tuberization. Higher rates of leaf production were, in general, maintained by nitrogen, small seed and by the omission of potash.

The/

The rate of leaf production is supposed to vary with temperature directly. The temperature coefficients approximated closely to the Van't Hoff's rule, in case of sugar beet and mangold. (Watson and Baptiste, 1938). There is nothing in the present data to suggest such a relationship with regard to the trends or the deviations from the trends. The reason will be immediately clear. The highest leaf production occurred in the first week of July, not on account of, but, in spite of the comparatively low temperature at that time. Apparently, the early rise was principally contributed by the mother tuber as indicated by the high depletion rates from it some time after emergence. After the middle of July when the role of the mother tuber was over, node production could be sensitive to the changes in temperatures if present but no marked variations existed to produce measurable effects, distinguishable from experimental errors. In August, node production could not be expected to show periodicity with temperature, on account of the drain of food material by the developing new crop of tubers.

FLOWERING :

The counts of flowering shoots of the plants, under height and node number observations, disclosed that more shoots were carried into flowering where nitrogen was applied (Table XLVI). Besides, visual observations showed that each shoot had more flowers in its cluster. Thus at the peak flowering period, N -plots stood out with dark green leaves and long flower-stalks bearing numerous flowers./

Table XLVI. Treatment effects on flowering shoots per hill.

	Early planting								Late planting								
	28/7	30/7	1/8	3/8	5/8	7/8	9/8	Possible	5/8	7/8	9/8	11/8	13/8	15/8	18/8	Final	Possible
n_0	0.7	1.0	1.25	1.25	1.4	1.45	1.5	5.6	.05	.55	1.15	2.1	2.9	3.4	3.95	4.4	7.0
n_2	1.1	3.0	4.15	4.35	4.65	4.75	4.85	5.9	.10	.50	1.1	2.4	3.85	4.8	5.55	6.3	7.8
k_0	1.0	2.05	2.85	3.0	3.35	3.40	3.55	5.3	.05	.50	1.15	2.15	3.45	4.25	4.90	5.3	7.8
k_1	.8	1.95	2.55	2.6	2.70	2.80	2.80	6.2	.10	.55	1.1	2.35	3.3	3.95	4.6	5.4	7.0
s	.35	.95	1.4	1.5	1.7	1.8	1.95	3.45	-	.20	.30	.40	1.0	1.55	2.40	3.20	3.85
l	1.45	3.05	4.0	4.1	4.35	4.4	4.4	8.05	.15	.85	1.95	4.1	5.75	6.65	7.1	7.5	10.95

Table XLVII. Interaction of factors on maximum dry matter (excluding tubers).

Dry matter (g. per plant)

Nitrogen and Potash

	n_0	n_2
k_0	40.0	66.5
k	40.0	87.0
diff. (±3.45)	-	20.5xx

Nitrogen and seed size

	n_0	n_2
s	30.5	69.1
l	49.5	84.4
	19.0xx	15.3x

Dates and seed size

	d_1	d_3
s	48.0	51.5
l	60.2	73.7
	12.2x	22.2xx

Dates and nitrogen.

	d_1	d_3
n_0	31.8	48.1
n_2	76.3	77.1
	44.5xx	29.0xx

flowers. The effect of nitrogen on flowering was however better marked under the early planting.

Potash apparently depressed flower formation in the early planting but not in the late. In either case it had no stimulating effect on flowering in confirmation of the effect on node number (the two are a measure of the same physiological process i.e. meristematic activity). The mean response to K and its differential behaviour with planting date were however insignificant. When the data were expressed as percentages of the possible, the differential response was brought out.

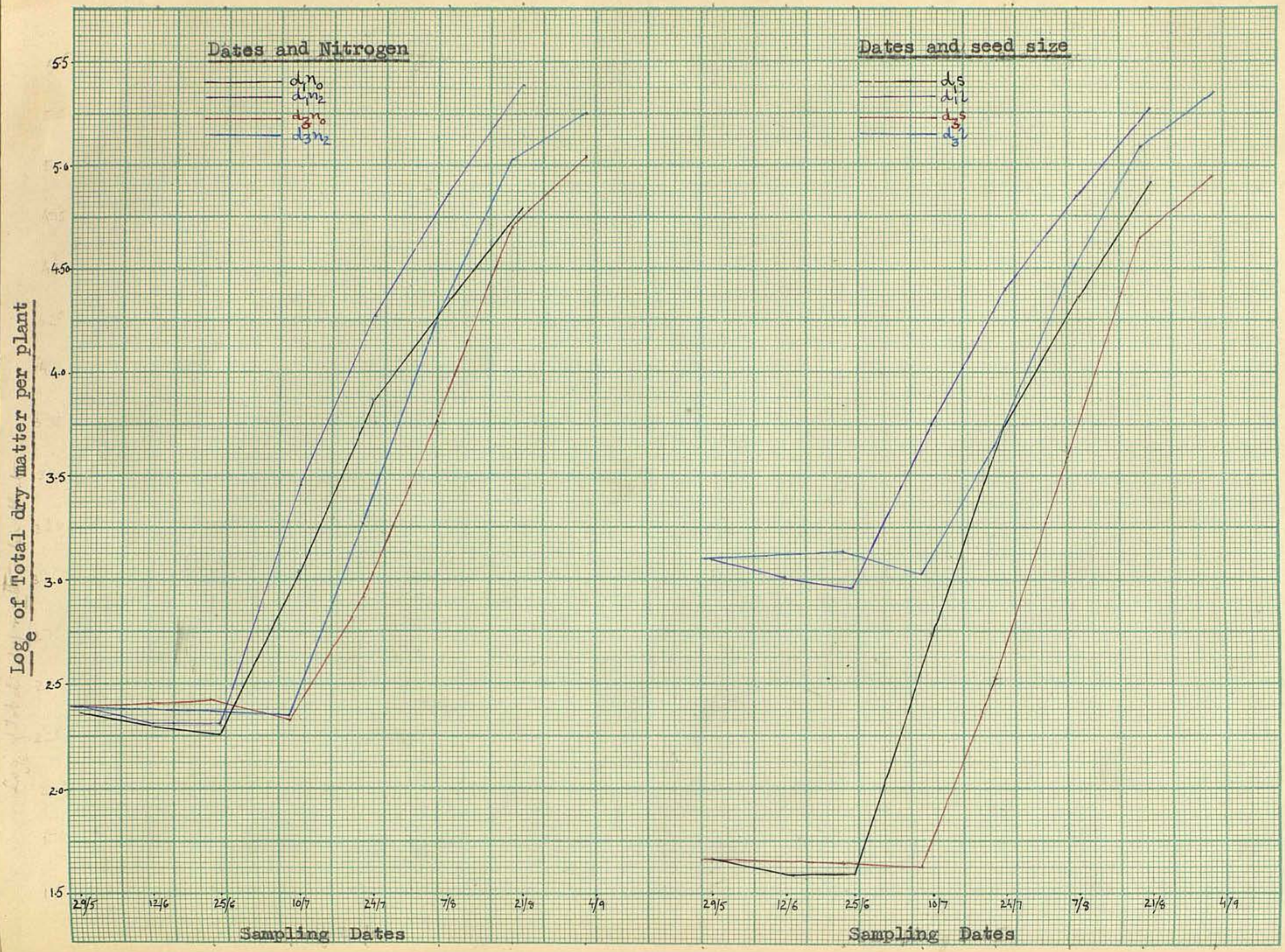
More shoots came into flowering from the large than from the small seed. This was to be attributed to more sprouts under large seed. On comparable basis, the proportion of shoots that flowered was more in the case of the small seed (cf. effect on node number) even though it initiated flowering later.

Late planting had distinctly greater flowering activity. When the allowance for variations in sprout number was made, the planting time effect was solely confined to plots not receiving nitrogen.

It was also observed that flowering activity was greatly inhibited on the heavy soil.

The mode of propagation in the potato being vetetative, in commercial growing, the effect of cultural conditions on flowering are of little direct agricultural value. They are, however, interesting from a physiological view point and also from the point/

Fig. 9 THE EFFECTS OF NITROGEN AND SEED SIZE ON THE RELATIVE GROWTH



point of view of breeding new varieties where recourse is had to the sexual reproduction.

Dry matter changes:

The values of total dry matter (all parts including the mother tuber) at the successive stages are plotted against time in Fig.10. To detect early differences better, natural logarithms of the actual values are also graphically represented in Fig.9, for the nitrogen and the seed size effect.

The total dry matter declined progressively till the sprouts appeared above ground, i.e. up to 12-13 June in d_1 and 23-24 June in d_2. This is to be expected for the growth proceeds to start with, at the expense of stored food, part of which must be lost in respiration. But even during the fortnight that followed, no increase in dry matter occurred in spite of the visible top growth. It was after 25-26 June in d_1 and after 8-9 July in d_2 that new material was incorporated in the plant body.

The effect of nitrogen, discernible towards the end of June in the first planting was registered conclusively on the sample taken on 10-11 July and a fortnight later in case of the second planting. The effects on height too appeared at about the same time. The effects of nitrogen on dry matter accumulated with time. The differences due to nitrogen were much higher under the early planting than under the late. The interaction D x N was significant statistically on total dry matter. The effect of the potassic manure/

point of view of breeding new varieties where recourse is had to the sexual reproduction.

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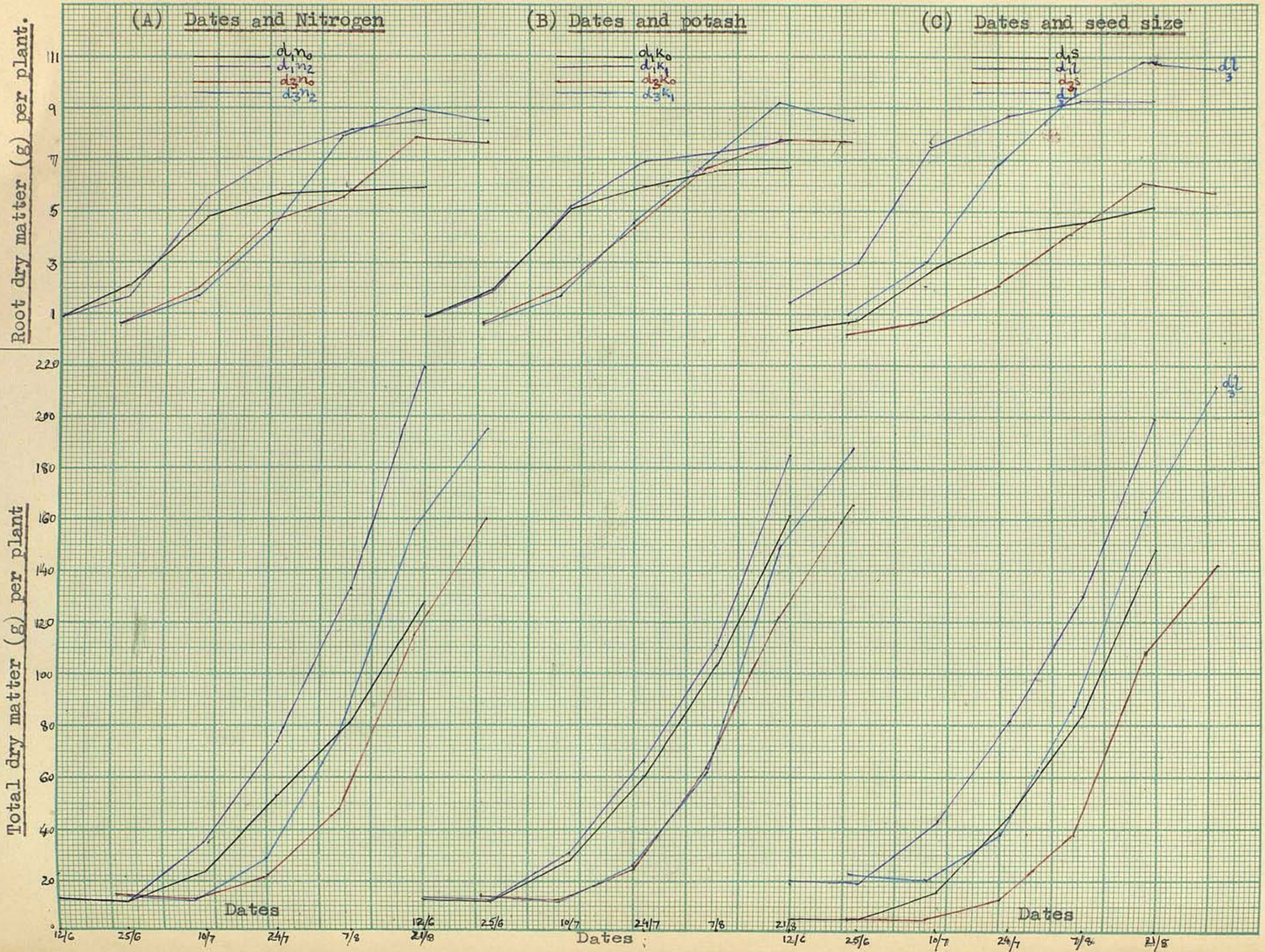
Fig. 10 TREATMENT EFFECTS ON TOTAL DRY MATTER AND ROOT DRY MATTER.



manure was rather meagre in the early stages. Only in the later stages was its effect established with certainty. The effect was equally marked in both the plantings. The interaction D x K was non-significant on dry matter, contrary to that on height.

Large seed gave a better start to the plants arising from them. The differences between the large and the small seed widened for a time after emergence and then persisted on the absolute growth basis. Thus the curves in Fig. 10 C tend to run parallel. Relative to the size of the seed, however, the gap between the plants arising from the two seed sizes became narrower and narrower (Fig.9 C) because of the compensatory growth in case of the small seed, discussed later.

Late plantings grew faster than the early. It may be noted that growth was strictly exponential in case of $\underline{d}_3$, in the absence of nitrogen or with small seed, over a period of time. Eventually the late planting produced the same amount of dry matter in the absence of nitrogen and thus covered up completely the disadvantage of 27 days' delay in planting. In the presence of nitrogen, however, the difference continued. The late planting profited less from nitrogen application. The D x N interaction pointed in the same direction on height, though it attained significance only on dry weight. If follows, therefore, that the differential behaviour was more pronounced on certain organs than others. The interaction D x K prominently brought out by germination, height and flowering/

flowering data, vanished completely in dry matter. The reason for this discrepancy is to be sought in the differential treatment behaviour on the plant parts.

As on height, the interaction N x K was highly significant on the vegetative development (Table XLVII). Potash was ineffective in the absence of nitrogen. Its speciality lay in reinforcing the effect of nitrogen. The main effect of potash on the output of dry matter derived its significance from the high response to this fertilizer,only in the presence of nitrogen.

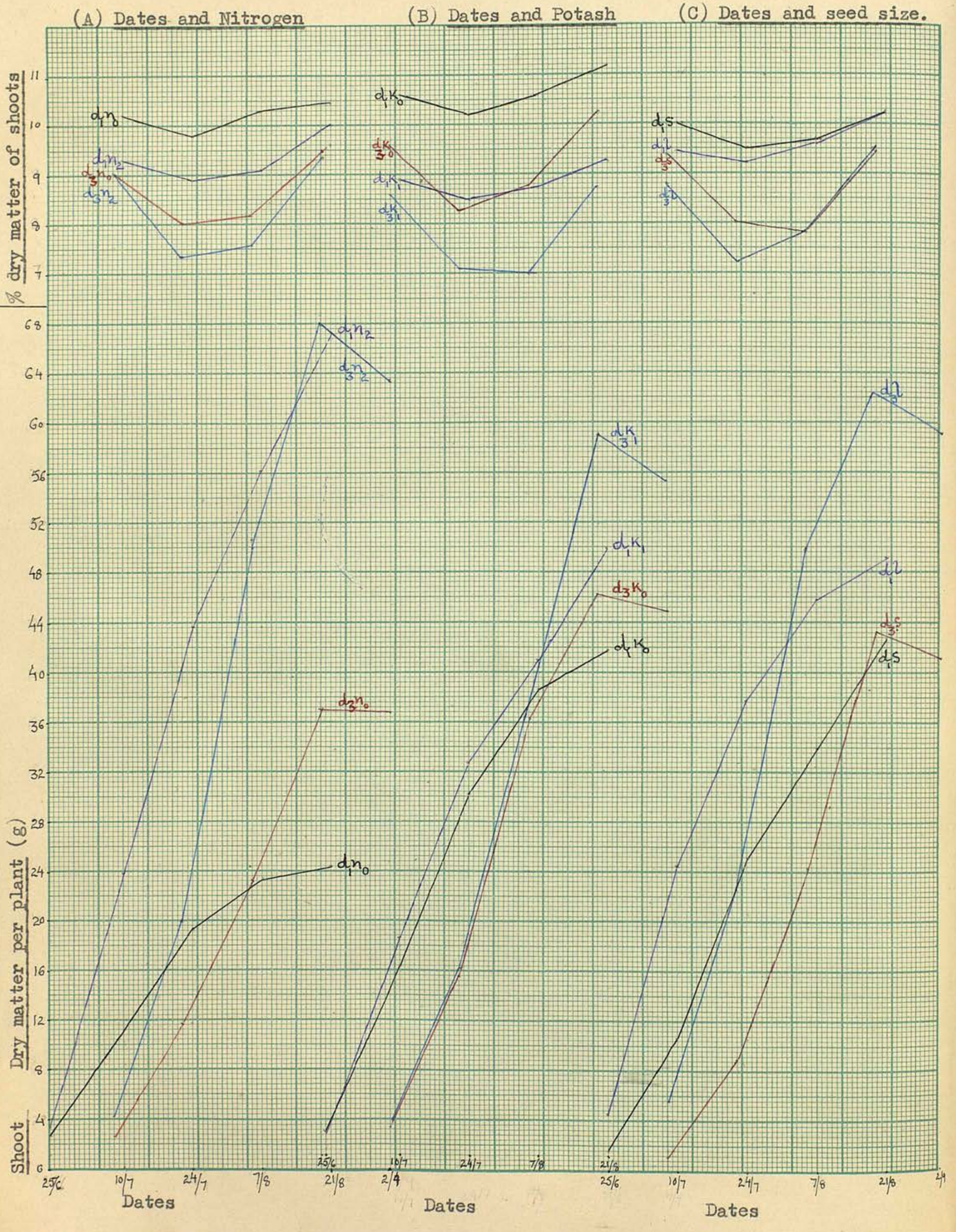
The greater carbohydrate reserves in the large seed did not enhance its responsiveness to nitrogen. Besides, the size of seed did not show a marked differential behaviour with the time of planting. The tendency of large seed to better the performance of the late planting is to be looked for in the D x S interaction revealed on sprout number (cf. Tables XXXVII and XLVII).

Treatment effects on total dry matter appeared sooner or later on the individual plant parts. The different parts differed in the magnitude of response.

<u>The Root and the Shoot:</u> Although the roots are the first to appear in the plant development, the fertilizer response on the root in case of nitrogen followed that on the shoot (cf. Fig. 10A & 11A), both in magnitude and in point of time. The effect of

Nitrogen/

Fig 11 TREATMENT EFFECTS ON DRY WEIGHT and DRY WT PER 100 gm FRESH WEIGHT OF HAULMS



nitrogen on the shoot began to show itself soon after the unfolding of the foliage by the end of June in d_1 when a depressive effect on the root was indicated. A positive effect on the root was registered a fortnight later and developed with time, but it was much smaller in comparison to the influence on the shoot throughout. The influences of nitrogen on the root and the shoot appeared in a similar form in the late planting. The delayed effect of N on the root is consequent upon the fact that the absorbed nitrogen must be assimilated in the shoot, to a greater proportion, before its effects are redistributed to the plant organs.

The case was different with the application of potash which influenced root as well as the shoot to a smaller extent, but at about the same time, and the root/shoot ratio did not appear to be materially influenced. This was apparently due to the ineffectiveness of potash in meristematic activity and consequently the aerial parts did not utilize the metabolites in abundance relative to the roots.

The effect of seed size on the root development appeared early and magnified with time, thus suggesting the role of extra food store in large seed in strengthening the root system. But as the root and the shoot are inseparable, the better developed root system from the large seed quickly reacts on the aerial development of the plants directly as well as indirectly; directly because the drain of carbohydrates from the tops/

tops to the roots may be partially reduced and indirectly through a better supply of nutrients and water from the ground early. Although, therefore, the root growth is influenced by seed size soon after sprouting, the effect on top growth quickly follows emergence. Bulk of the effect of seed size on the top growth and the underground development is the direct outcome of its influence on the number of sprouts.

The differential behaviour of nitrogen with planting date was recorded on the root as well as the shoot. On the shoot, this effect resembled that on the height.

Late planting was conducive to the production of greater dry matter of the root and the shoot, in the absence of nitrogen. In the presence of nitrogen, the two plantings were very nearly equal in vegetative development. It is possible that this effect may have been modified if the weather conditions were normal. The nitrogen-treated late crop did not get a chance of a fuller expression in growth on account of the check it received due to the prolonged drought in August.

The effect of potash on the shoot dry matter tended to be greater in the delayed planting.

<u>The Dry Matter content of haulms:</u> The effect of the four factors on the fresh weights were even better marked that those on dry matter discussed above, for all factors, viz., nitrogen, potash, late planting and large seed, raised the water content of the plant at most/

most of the stages. Conversely, they reduced the dry matter content ($\frac{\text{Dry Matter}}{\text{Fresh wt.}}$ x 100) as shown in Fig. 11 (upper half).

The effect of nitrogen on the dry matter content tended to diminish in the later stages as a result of water shortage in August. Towards the end of August and early September the effect of nitrogen must have been completely nullified, as evidenced from the more pronounced drooping of leaves under N - fed conditions due to the severity of drought. The relative abundance of proteinaceous matter and the reduction of the thickening and strengthening tissues under N-treatment make for better cell turgidity only if the water supply is adequate. In fact a N- treated plant is an easier victim to drought as it depletes the soil moisture relatively early through greater transpiration losses from its larger leaf area. In addition the drooping of leaves, consequent upon the lack of strengthening tissue, will be expected to interfere with the assimilatory activity of the leaves.

The effect of the muriate of potash on the water content of the plants was infallible. This treatment undoubtedly led to greater succulence at all stages. During the period of severe drought (when the data for fresh weight were not recorded) this treatment was observed to correct the drooping symptoms under heavy dressing of nitrogen. The data for the effect of muriate of potash on the internodal length also points in the same direction. There appears to be little doubt/

doubt that this effect was directly or indirectly caused by the Cl^--ion, and not the K^+ (see e.g. James 1931). The tendency for succulence in the plants growing under saline conditions where chlorine is one of the ingredients is also evidence in this direction. The characteristically high water content of the chlorine-loving plants, such as mangold and sugar beet, is again a striking example of the relation between Cl^- and water content. The effect of the muriate appears to be independent of the soil moisture supply, for it was obtained at all stages of sampling. It also does not vary with the time of the day (Watson, 1936). The way in which Cl^- ion locks up water in the plant should be an interesting problem to investigate.

Large seed facilitated the entry of water (or it reduced the dry matter content) in the plant in the earlier stages, suggesting better root development and more efficient soil exploration. But the effect declined rapidly with the advance of time and disappeared altogether even before the plants were subject to the full impact of the drought conditions. This was evidently due to the internal competition for water between the various plant organs. Large seed provided for an earlier and a larger potential crop of tubers, which competed with the tops for water relatively earlier. Late in August, it is possible that the moisture content of the plants from large seed was lower than those from the small seed on account of the strained water relations of the plant.

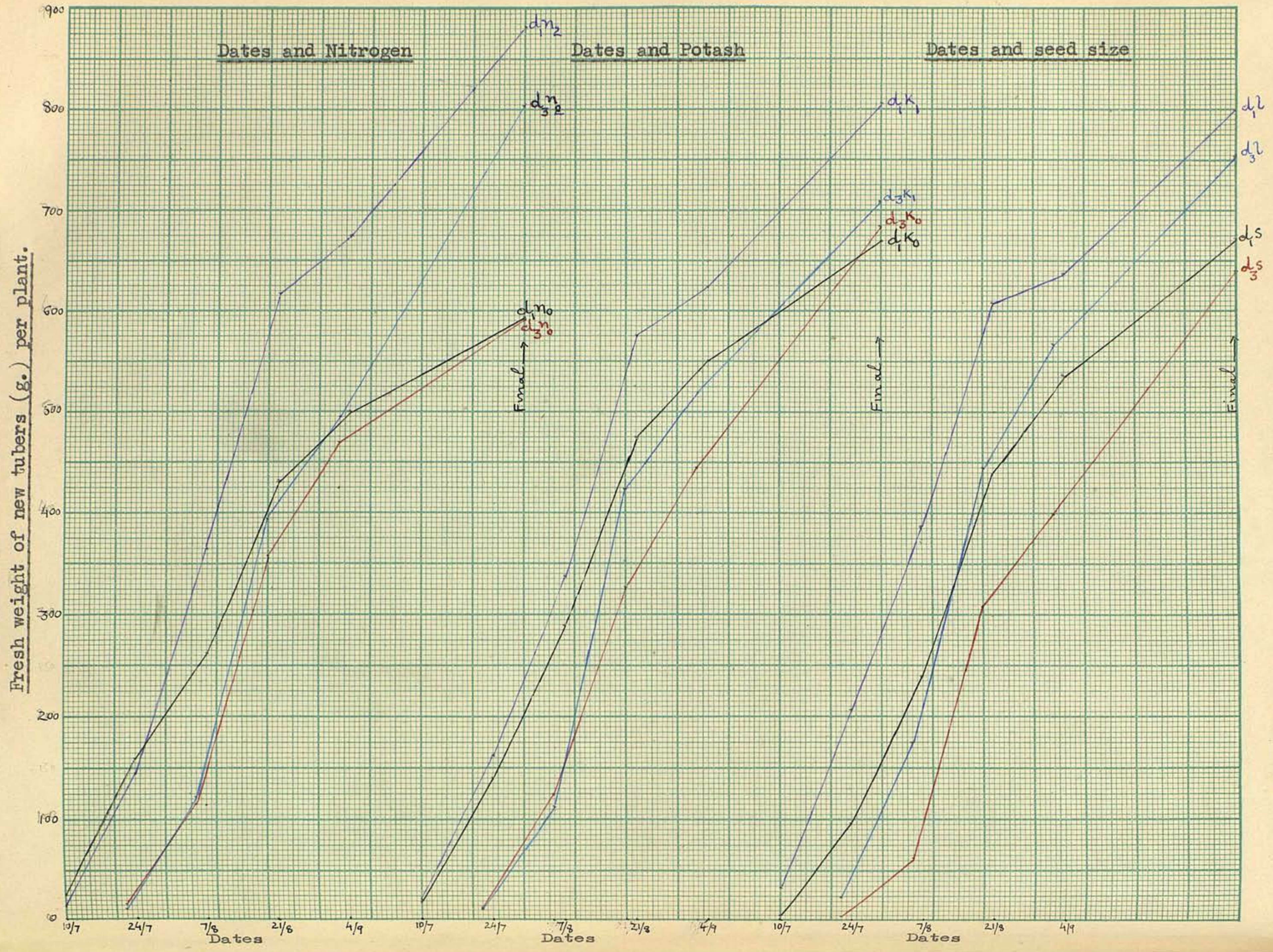
Not/

Not only is the internal competition severer in the plants from large seed, but there are greater soil-moisture losses through larger transpiration surface. Observations revealed that the drought conditions told rather heavily on the plants from large seed.

Late plants were fresher and more succulent when compared with the early planting at the same sampling stage. Even when the two plantings were compared at similar stages of morphological development (to get over the age effect) the essential differences remained, despite the complication introduced by the varying enviromental conditions, involving comparisons on this basis. Late plantings had a distinct tendency to grow vegetatively and correspondingly the tops tended to draw more heavily on water before the drought conditions were serious.

It is interesting to note that the treatment effects on the length of internodes discussed on p. 80 - 81 were just a reflection of similar effects on the dry matter content (or water content indirectly). The causal relationship between the water factor and the expansion phase of growth is thus convincing. It may, however, be pointed out that the above data relate to the early morning samples when the water deficit caused in the plants during the previous day tends to be restored. It is ,therefore, possible that effects of nitrogen, large seed or late planting on dry matter content may be obliterated or, at any rate, lessened in the afternoons, specially under/

Fig 12 TREATMENT EFFECTS ON THE FRESH WEIGHT OF NEW TUBERS.



under conditions of prolonged drought. The effect of 'muriate' should, however, endure as indicated earlier.

The Fresh weight and the dry weight of the tubers:
Tuber formation commenced in about three weeks from the emergence of sprouts above ground (Figs.12,13). The sprouts from large seed established early and they were the first to tuberize. Nitrogen had a slight delaying effect on tuberization. The delay in the initiation of tuberization by a shift in planting time was not equivalent to the interval between plantings but approximated closely to the length of delay in respect of sprout emergence.

The effects of nitrogen and potash on the crop of tubers were similar to those obtained on the vegetative parts.

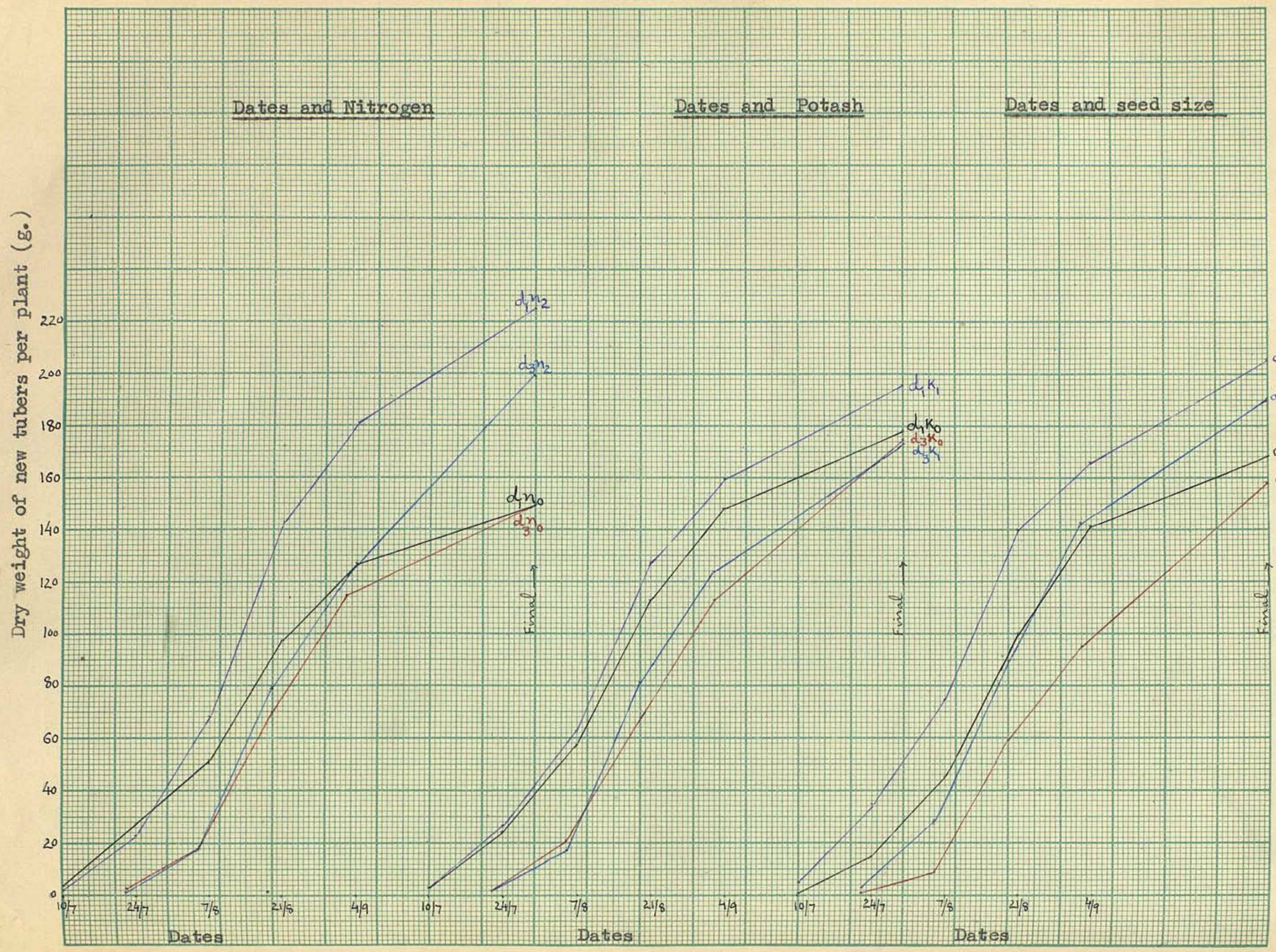
Large differences gradually developed with nitrogen in the early planting, both on the fresh weight and the dry weight of the tubers. In the later planting, the effect of nitrogen came slowly and did not rise high.

Potash had a consistent, though small, effect on the fresh crop which scaled down considerably in dry weight.

The effect of large seed was marked on the new crop in the two plantings. There was no evidence of any special benefit accruing to the late planting.

The effect of planting time deserves special mention. Although the late planting had outgrown the early/

Fig 13 TREATMENT EFFECTS ON THE DRY MATTER OF THE NEW TUBER

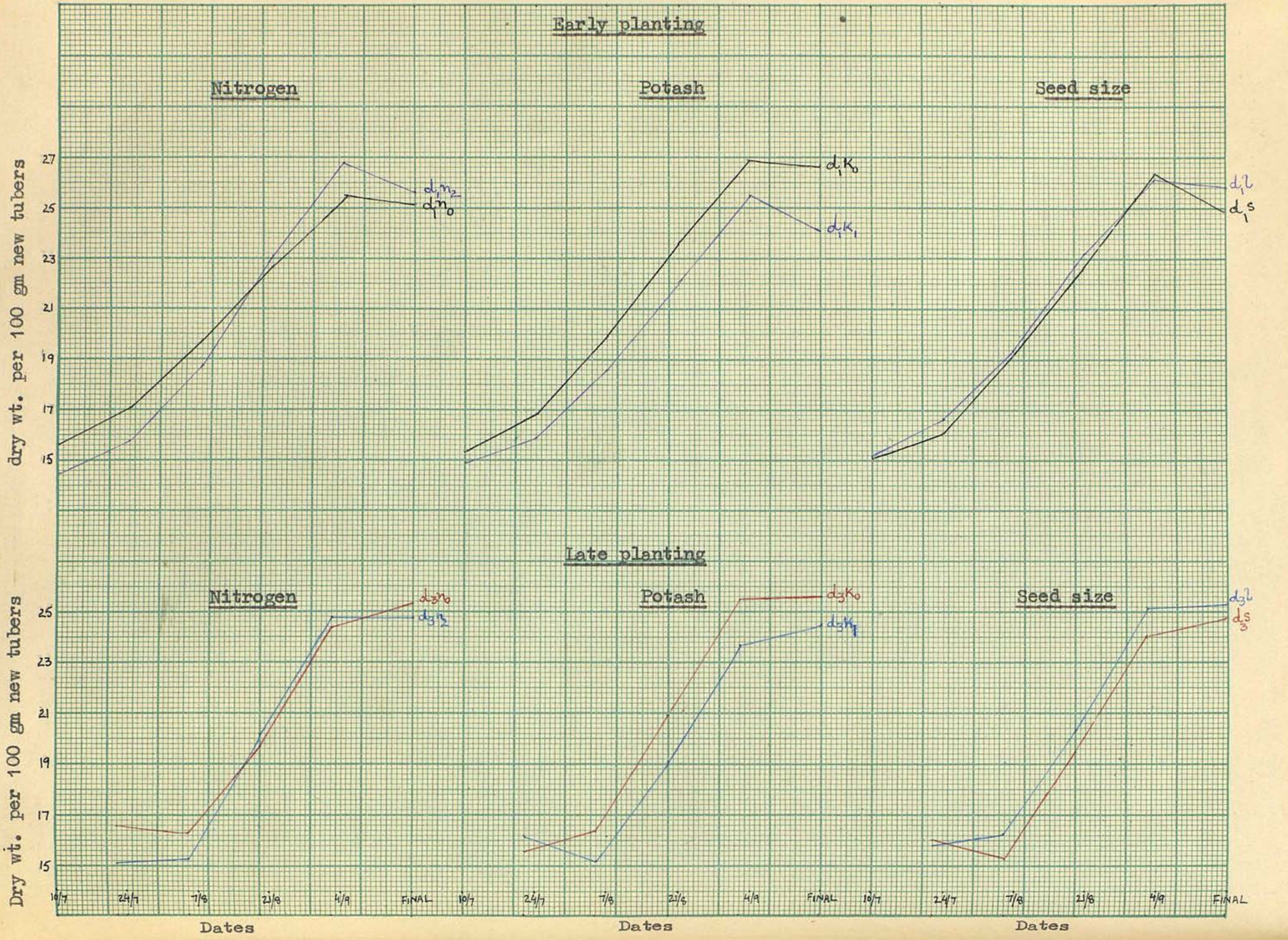


early in height, fresh weight and the dry weight of the vegetative parts in the absence of nitrogen, it just got level with it in the matter of tuber production. In the presence of nitrogen, although the late planting equalled the early in growth, it fell short of the high level of tuber yield reached by the early planting. In either case, therefore, the "storage efficiency" of the late crop was low.

Dry Matter content of the Tubers: The dry matter expressed as a percentage of the fresh weight of the crop of tubers is given in Fig. 14. The dry matter rose from about 15% to 27% during the storage phase. The steep rise was partly contributed by the prevailing drought in August. So great indeed was the internal competition for water under conditions where the potential crop was heavy that some of the small tubers were virtually 'sucked back' - their contents hydrolysed and largely translocated. Although the tubers did not grow to their full size, they were richer in dry matter by about 5% as compared with the preceding year. This fact should not be lost sight of in judging the size of the crop in the year under report.

Nitrogen reduced the dry matter concentration of the tubers in the early stages. Later the effect vanished or was reversed depending upon the size of the new crop and the availability of water. As more tubers were enlarging in the early planting treated with nitrogen, the competition for water limited their/

Fig. 14 TREATMENT EFFECTS ON DRY MATTER CONTENT OF THE NEW TUBERS



their water content much before the same effect showed up in the late planting.

The muriate of potash depressed the percentage of dry matter consistently and conclusively in either of the two plantings. The average decrease was 1.2% Thus the influence of potassium chloride was recorded on water content in case of the vegetative as well as the storage parts. Reference may here be made to an interesting experiment by Commoner et al (1943). Thin discs of potatoes were immersed in a hypertonic sugar solution and they lost water. Little loss occurred when 10 mg. Indole-3-acetic acid was added. With the addition of potassium chloride with the auxin, the discs actually absorbed water. This lends confirmatory support to the evidence of the influence of the muriate of potash on water absorption.

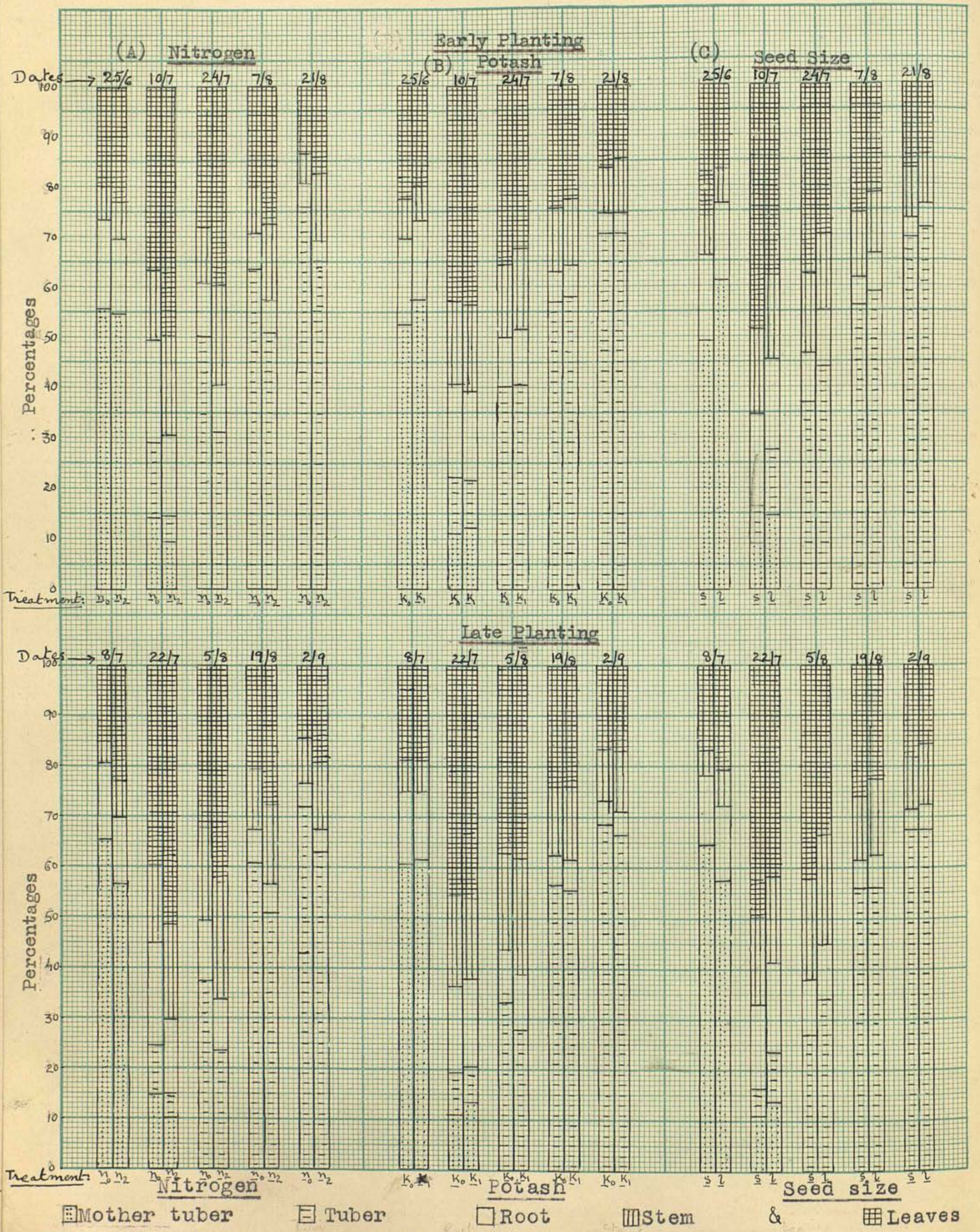
Seed size produced only a small effect on the dry matter percentage. The tubers from large seed were comparatively richer in dry matter. As greater number of tubers were developing from the large seed, the effect is explicable in terms of competition. for water.

The dry matter content of the late crop tubers compared favourably with the early planting at the comparable stages, and also finally.

<u>The Relative distribution of total dry matter in parts:</u>

A consideration of the distribution of dry matter has two main aspects (1) The changes in the distribution of dry matter in parts with time (2) The treatment effects/

Fig. 15 RELATIVE DISTRIBUTION OF TOTAL DRY MATTER IN PARTS



effects in modifying the trends. The treatment effects should usefully be studied with reference to (a) The root/shoot ratio which is a measure of the efficiency of the plant for soil exploration (b) The ratio of the assimilating material to the total plant body, which in part controls the efficiency of the plant for the production of new material (c) The proportion of tubers to the total dry matter or 'storage efficiency' which determines the extent to which the effects on growth will lead to a commercial advantage.

The general trends in the distribution of dry matter can be simply followed from Fig. 15B, for the position is eased by the relatively small part played by potash in modifying the trends. While the mother tuber depleted rapidly after sprouting and the new tubers increased progressively after the onset of tuberization, the proportion of leafy material increased for a time and then fell off as the season advanced. The implications of this will be discussed in the next section. The stem proportion was correlated with the leaf percentage.

Nitrogen influenced the shoot/root ratio at all stages and in either of the two plantings. (Fig 15 A). Besides it stimulated the leaf fraction at all stages and lowered the 'storage efficiency'.

The distribution in the early stages was characterised by a relative diminution of the dry matter content of the mother tuber caused by nitrogen application. (This is not necessarily suggestive of enhanced depletion from/

from the mother tuber induced by nitrogen.) The muriate of potash appeared to exercise the reverse effect. Effect of potash on the stem proportion seemed positive.

Strangely enough, the relative distribution between foliage and tubers was differently affected by the potassic fertilizer in the two plantings. With the early planting, it depressed the foliage (cf. effect on node number) and maintained the tuber proportion. With the late planting, the converse held true.

The effect of seed size was consistent in that irrespective of the planting time and the stage of sampling the leaf fraction decreased with the increase in seed size. On the other hand, the tuber proportion increased with seed size but the differences lessened with the advance of time and the delay in planting. The storage efficiency of the small seed improved with time so that at maturity it exceeded that of the large seed (Table XLVIII). The final tuber weights have been worked out as percentage of the maximum dry matter (Final tuber weight + maximum dry weight of the vegetative organs).

The under-ground organs were proportionately better developed as seed size increased but Fig.15 C, furnishes little evidence of higher root/shoot ratios in favour of large seed, suggested earlier. The effect was obscured by including the mother tuber in the calculations./

Table XLVIII. Storage efficiency percentage under different conditions finally.

$$\frac{\text{Tuber dry matter}}{\text{maximum dry matter}}$$

Dates and nitrogen	d_1	d_3	Dates and potash	d_1	d_3	Dates and seed size	d_1	d_3
n_0	82.7	75.8	k_0	79.0	75.8	s	79.4	75.7
n_2	74.5	72.4	k	78.3	72.2	l	77.9	72.4

Table. XLIX. Root/shoot Ratios (as percentages)

	Early planting				Late planting			
	25/6	10/7	24/7	7/8	8/7	22/7	5/8	19/8
s	50.5	26.3	16.4	13.6	60.6	23.4	17.0	14.1
l	66.1	30.7	23.1	20.4	53.1	30.0	18.9	17.4

Table L. Growth rate just after emergence

	Early Planting				Late Planting			
	12,13/6 - 25,26/6				24,25/6 - 8,9/7			
Treatments	E.I.	L.W.R.	N.A.R.	Days above ground	E.I.	L.W.R.	N.A.R.	Days above ground
s	-.041	.152	-.271	10.8	-.074	.109	-.680	9.3
sn	.008	.148	.055	12.3	.108	.135	.794	8.6
sk	-.060	.140	-.431	12.9	.045	.107	.422	6.8
snk	.154	.126	1.215	11.9	.107	.119	.896	7.4
l	.049	.057	.856	13.2	-.093	.050	-1.839	10.4
ln	-.105	.061	-1.713	12.1	.028	.075	.374	12.2
lk	-.016	.047	-.333	13.2	-.165	.055	-3.000	11.2
lnk	-.006	.072	-.085	16.5	-.174	.076	-2.290	11.6

calculations. A straight computation of the root/shoot ratio brought out the expected relation prominently (Table XLIX).

The late crop had lower storage efficiency as compared with the early planting right to the end (Table XLVIII). The proportion of the vegetative organs was correspondingly higher.

GROWTH ANALYSIS.

The relative rate of increase in dry matter or the efficiency index (E.I.), the leaf-weight ratio (L.W.R.) and the net assimilation rate (N.A.R.) were worked out by the following formulae according to the methods developed by Blackman (1919), Briggs et al (1920) and Gregory (1926). Leaf weights were employed instead of leaf areas for these calculations.

$$\text{Efficiency index (E.I.)} = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

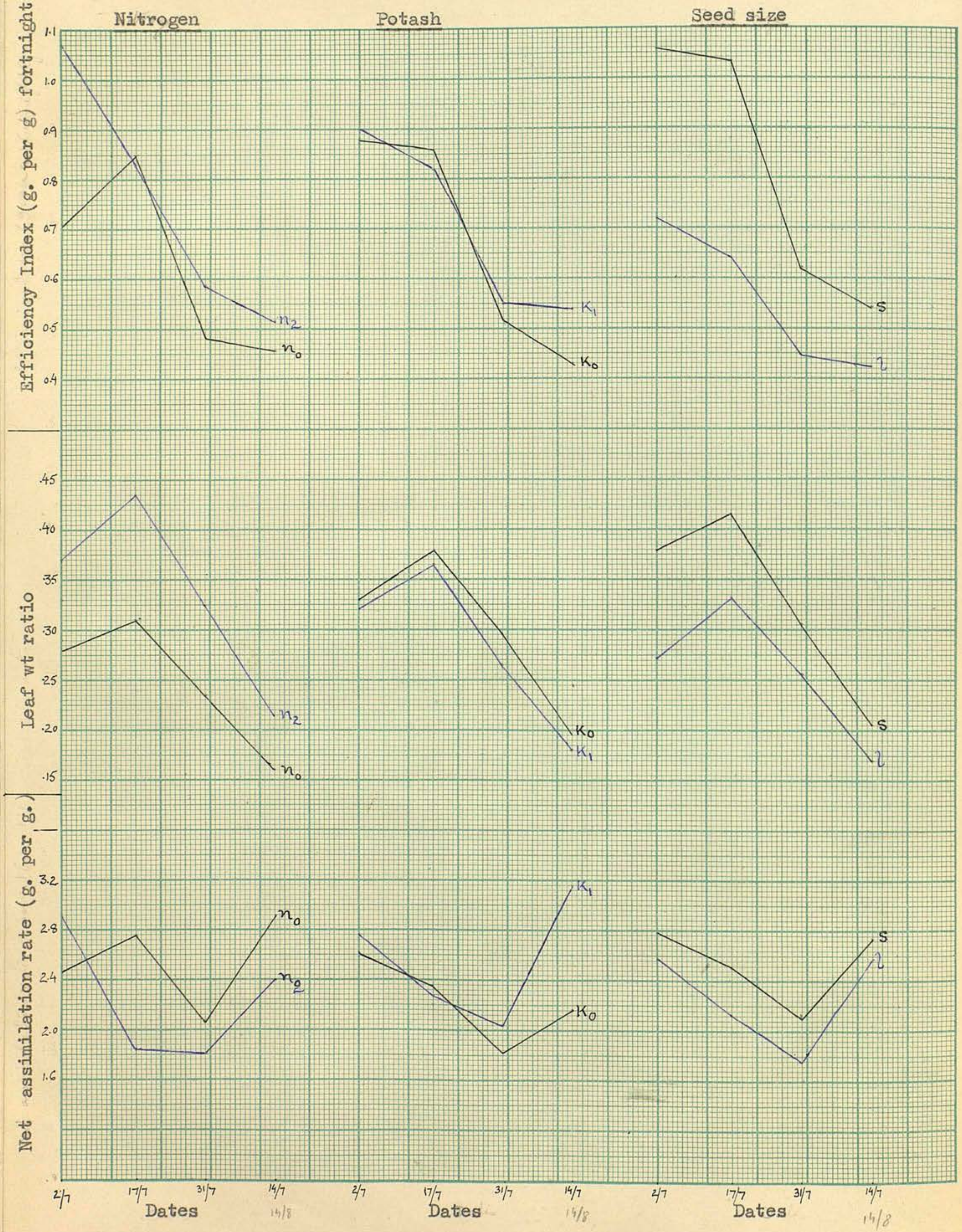
$$\text{Leaf-weight ratio (L.W.R.)} = \frac{L_2 - L_1}{\log_e L_2 - \log_e L_1} \times \frac{\log_e W_2 - \log_e W_1}{W_2 - W_1}$$

$$\text{Net assimilation rate (N.A.R)} = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\log_e L_2 - \log_e L_1}{L_2 - L_1}$$

Where W_2 and W_1 represent the dry weights and L_2 and L_1 the leaf weights at times t_2 and t_1 (i.e. the consecutive sampling stages). In the present case, the rates were calculated per fortnight (which was the interval between sampling) unless otherwise stated.

The efficiency index may be defined as the rate of increase in dry matter per unit of material per unit/

Fig. 16 TREATMENT EFFECTS ON GROWTH RATES (EARLY PLANTING)



unit of time. It is the product of the two components - leaf weight ratio and the net assimilation rate. The former is a measure of the size of the assimilating material and the latter, of the intensity of assimilation per unit leaf area or leaf weight.

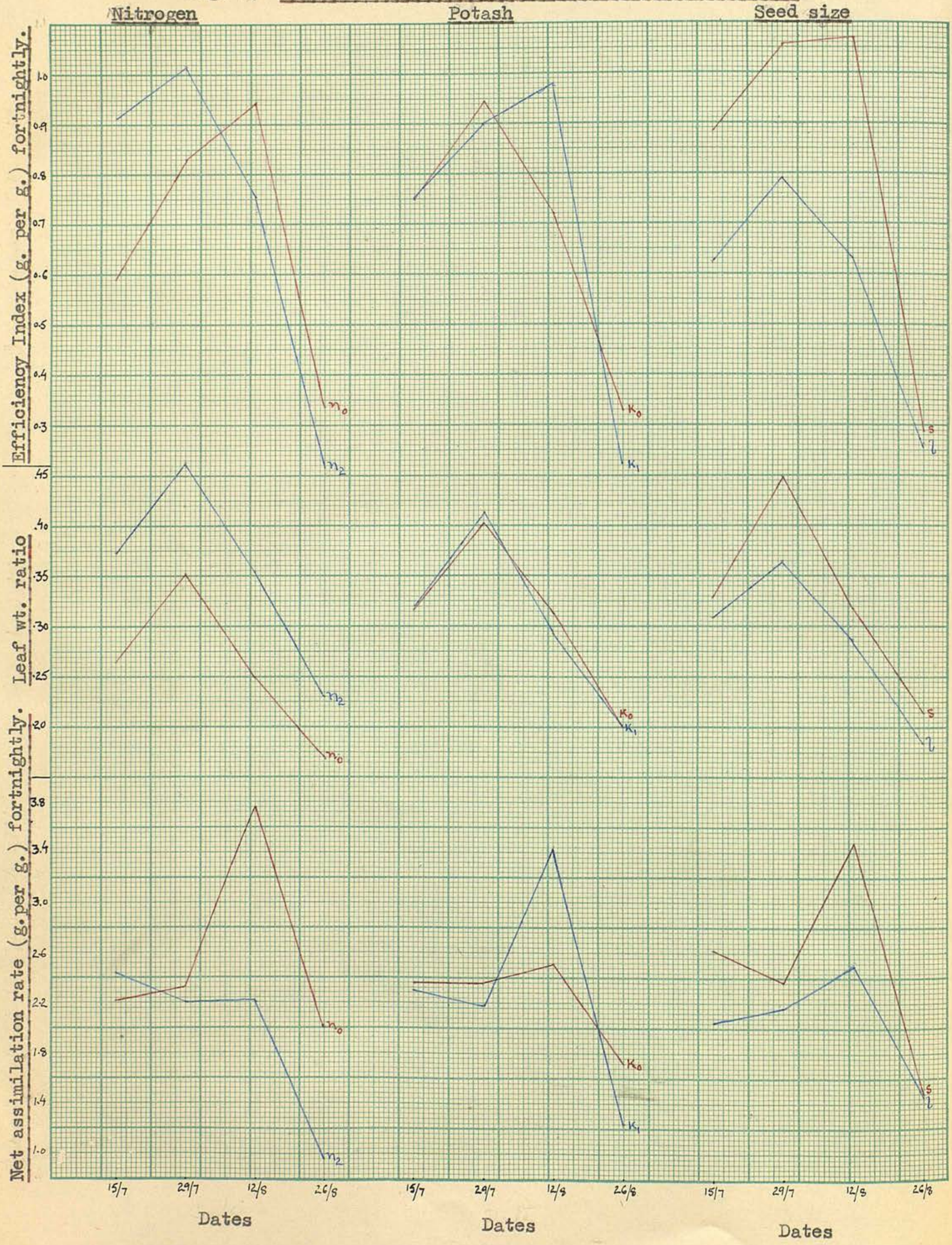
Progressive changes in Growth rates:

The curves for efficiency index had invariably a preliminary rise, occurring sooner or later depending upon the conditions (Figs.16 and 17). The efficiency index however fell off steadily and even when the leaf growth rate ceased, the output of dry matter continued on account of the photosynthetic activity of the leaves.

The general shape of the curves for efficiency index (inverted S. shaped) resembles that for other plants with the difference that the maxima exhibited towards the reproductive phase in the other plants such as maize (Briggs et al, 1920, Dastur and Singh,1943) were absent in the present case. The data of James (1931) for potato planted late,and of Watson and Baptiste (1938) for sugar beet and mangold,were also conspicious by the absence of later maxima. Possibly all root crops and potatoes will behave in this manner, as contrasted to the crops which fruit and flower.

The preliminary rise in the efficiency index after the completion of germination, is to be attributed to two factors which operate irrespective of the species of the plant or its variety and other conditions. Firstly,/

Fig. 17 TREATMENT EFFECTS ON GROWTH RATES (LATE PLANTING)



Firstly, the size of the assimilatory system given by leaf-weight ratio invariably increases over a period of time following emergence. In the present case, leaf-weight ratio reached a maximum about four weeks from the mean date of emergence and the incidence of maximum was not modified by a change of conditions. Secondly, the rate of assimilation shoots up on the completion of emergence, from zero or negative values during germination. A reference to Table L reveals strikingly that during emergence, from 12/6 to 25/6 in d_1 and 24/6 to 8/7 in d_3, when leaves formed 5-15% of the total plant body, the net assimilation rate was nil or negative. In other words, the real assimilation by the foliage was so low that the respiration losses outweighed it altogether. This result is in complete agreement with that brought out for maize by Briggs et al (1920) from Kreusler's data, and also borne out by direct measurements of the assimilation rates of the young leaves (Briggs 1920, Irwing, 1910). It is all the more interesting that the greater feeding power of the mother tuber in the potato enabling a quick set-up and rapid leaf expansion as compared with the crops raised from true seed, should exhibit it, even more prominently. In fact the increase in 'seed' size discloses the relative ineffectiveness of photosynthetic mechanism, in the early stages, still more convincingly. It appears there is a distinct time lag between the outward formation of the structure of leaves and the setting up/

up of the organization of the photosynthetic apparatus and a lot of food is expended in respiration during the formative stage and the young sprouts make heavy demands on the mother tuber as shown earlier.

When the photosynthetic apparatus is completely organized, further changes in assimilation rate have no time relation. (Figs. 16 and 17). This is further confirmed by the fact that when the curves for the N.A.R. in case of the late planting are suitably shifted to compare with the early planting on the same age from emergence they do not overlap. Assimilation rates fluctuate widely contrary to the regular linear fall in the leaf weight ratio throughout the tuberization phase. The relative rate of increase in total dry matter (E.l.) may therefore fall rapidly, gradually or most slowly, depending upon the modifying influence of the assimilation rates on the falling trend to be expected from the leaf-weight ratio.

The strict regularity of the shape of the curves for leaf-weight ratios, immutable by any of the factors, at once suggested that this component was controlled by the internal factors. (Treatments producing the maximum divergence in leaf-weight ratio did not modify the incidence of the peak or the rate of the subsequent fall). On the contrary, fluctuations in the assimilation rates were no doubt caused by the varying environmental conditions. A comparison of the assimilation rates, in the absence of nitrogen, for the early planting, with the weather factors revealed that the/

that the assimilation rose or fell with the values for the hours of sunshine (Table L1). The hours of sunshine themselves varied largely with the day temperatures, as is to be expected. It is, therefore, not possible to separate out the two effects. It was probably the co-ordinating influence of the two factors, temperature and radiation, which brought about high rates of assimilation towards the middle of July. The leading role of the light factor is suggested by a decline in assimilation during the fortnight 25/7 to 7/8 as compared with the preceding one, for the temperatures were of the same order. That this decline was not caused by the water factor, which might be suggested from the low rainfall during the above mentioned fortnight of decreased assimilation, could be readily proved from the concurrence of peak assimilating rates with the period of the least rain-fall (8 - 21 August). The soil moisture was apparently never so low as to limit assimilation in the absence of nitrogen, up to the third week of August. The position was different in the end of August and the beginning of September when the internal water relations of the plant were greatly strained under the influence of continued drought. A wide-spread wilting of the leaves occurred - developing gradually from localised areas of heavy soil. (The nitrogen-treated plants not being rigid in structure appeared to suffer still more). The rates of assimilation therefore fell off steeply, even though temperatures and duration of/

Table LI. The relation of net assimilation rate with external factors (in the absence of nitrogen mean values per day.)

	Early planting				Late planting			
	26/6-10/7	11-24/7	25/7-7/8	8-21/8	9/7-22/7	23/7-5/8	6/8-19/8	20/8-2/9
Net assimilation rate (gm. per gm.)	.176	.198	.147	.209	.159	.166	.268	.143
Hours of sunshine.	4.82	5.44	4.06	8.1	5.34	4.16	7.45	8.77
Maximum temp. (^{o}F)	63.1	67.2	66.2	70.8	66.8	66.4	69.9	70.9
Rain (mm).	1.72	4.31	1.41	.09	4.88	1.41	.09	-

Table LII. Interaction nitrogen and potash with time on net assimilation rate (per week calculated)

	Early planting				Late planting			
	26/6-10/7	11-24/7	25/7-7/8	8-21/8	9/7-22/7	23/7-5/8	6/8-19/8	20/8-2/9
$n_0\ k_0$	1.23	1.51	.93	.97	1.21	1.22	1.56	1.15
n_2	1.39	.84	.89	1.19	1.15	1.14	.96	0.58
k	1.23	1.26	1.13	1.96	1.00	1.11	2.19	.85
$n_2\ k$	1.52	1.01	.92	1.19	1.30	1.06	1.24	.39

of bright light were more favourable than ever before. The data for this observation are available for the late planting alone but doubtless the same relation held true in the case of the early planting. The temperatures were occasionally supra-optimal to cause a disproportionate increase of respiration and influence the photosynthetic/respiratory ratio adversely. The optimum temperature for photosynthesis in the potato is 20° c (68°F) and that for respiration 35°C (95°F), according to Lundegardh (1931). In the current year, the maximum temperatures often went above 70° F, but this must have occurred over brief periods of the day. The indirect effects of solarization and the reduced hydration of the mesophyll cells and the guard cells, apparently, exercised the controlling influence. The physiological role played by water in photosynthesis is well known (Dastur 1924, 1925).

The peak rate of assimilation synchronising with the high temperatures and radiation in the middle of August was most marked in the late planting in the absence of nitrogen. But the assimilation rates on the two preceding stages (23/7 to 5/8 vs. 9-22/7) did not conform to the corresponding light duration or temperature. The reason is not far to seek. The plants had not yet completed the preliminary period of low assimilation rates which influenced the mean rate during 9-22/7.

In the presence of nitrogen, the relations between/

between assimilation and weather factors are complicated by the operation of a time factor causing shading of leaves and it is not easy to isolate the influence of shading. A regression on the order of time might to some extent help but it will at the best be an approximation.

Treatment effects on growth rates:

The leaf-weight ratios were influenced favourably by nitrogen, under either of the two plantings. The net assimilation rates were raised to higher values by nitrogen during the fortnight following leaf expansion, but throughout the rest of the period the assimilation rates were never as high under nitrogen application as under untreated plants. The effect of nitrogen in assimilation therefore changed sharply with time. The early rise was, apparently, due to the effect of N in unfolding the leaves and setting up the photosynthetic apparatus relatively earlier and in spacing the leaves (by the elongation of the internodes) for easy access to light and carbondioxide. The lower assimilation rates which quickly followed were in all probability caused by 'shading' resulting from profuse foliar growth. The influence of nitrogen on assimilation rate is of considerable interest and has been the subject of some controversy (Gregory, 1937). Gregory (1926) claimed that net assimilation rate was mainly controlled by the external factors and was uninfluenced by nitrogen. Direct measurements of assimilation rate confirmed this finding (Chinoy, 1935;/

1935; Gregory and Richards,1929). Other workers quoted by Gregory (1937) found a decrease in assimilation with nitrogen deficiency. This discrepancy was attributed by Gregory to the influence of nitrogen deficiency on the senescence of leaves - a factor which was not taken account of by the workers who obtained different results. It may,however,be mentioned that the above investigations relate to pot-culture experiments where shading or inaccessibility of light under N-treatment, apparently, was not allowed to interfere with the determinations for carbon-assimilation. Under field conditions, the shading of leaves caused by nitrogen would, no doubt, lower the assimilation rates. A similar result has been quoted by Heath and Gregory (1938) for thickly-sown grasses.

It may be restated that leaf-weights instead of leaf areas were used in the computation of growth analysis in this investigation. As assimilation rate is a function of leaf surface rather than leaf weight, some appraisement is necessary to judge the influence of this basis on the results. It would be normally expected that nitrogen would increase the $\frac{\text{leaf area}}{\text{Leaf weight}}$ ratio, so that rates of assimilation on leaf area basis would be lower than here presented. This may also bring down the earlier superiority of nitrogen on the assimilation rate. Thus the reduction of assimilation rate would figure out even more prominently. Correspondingly, the leaf area ratio to the total dry matter would be influenced by nitrogen to a greater extent/

extent than suggested by leaf-weight ratios.

It is note-worthy that a higher efficiency index under nitrogen in the present experiment, was contributed largely by higher leaf-weight ratio, in the early stages. In the later stages, reciprocal influences on the two components cancelled each other so that relative leaf growth rate was not materially influenced.

The muriate of potash did not raise the leaf weight ratio in any of the two plantings. It had a small but consistent depressant effect on leaf-weight ratio under the early planting. The differential behaviour of muriate with planting date has been obtained throughout the development in one form or other. It appears that K Cl exercised its influence through the separate effects of ions K and Cl. The first planting took a longer time to sprout so that some of the chloride was washed down and the potash ion predominated in effect in the early planting, and leaf production was inhibited, an effect known for potash. In the late planting, sprouting was not much delayed so that both K and Cl^- exercised their effects in due measure. It appears that the Cl^- ion did not inhibit leaf production.

The muriate of potash had no effect on the net assimilation rate in the early stages but it had a very high effect during the fortnight when peak assimilation rates were recorded i.e. during the period characterised by bright, sunny, warm dry period.

According/

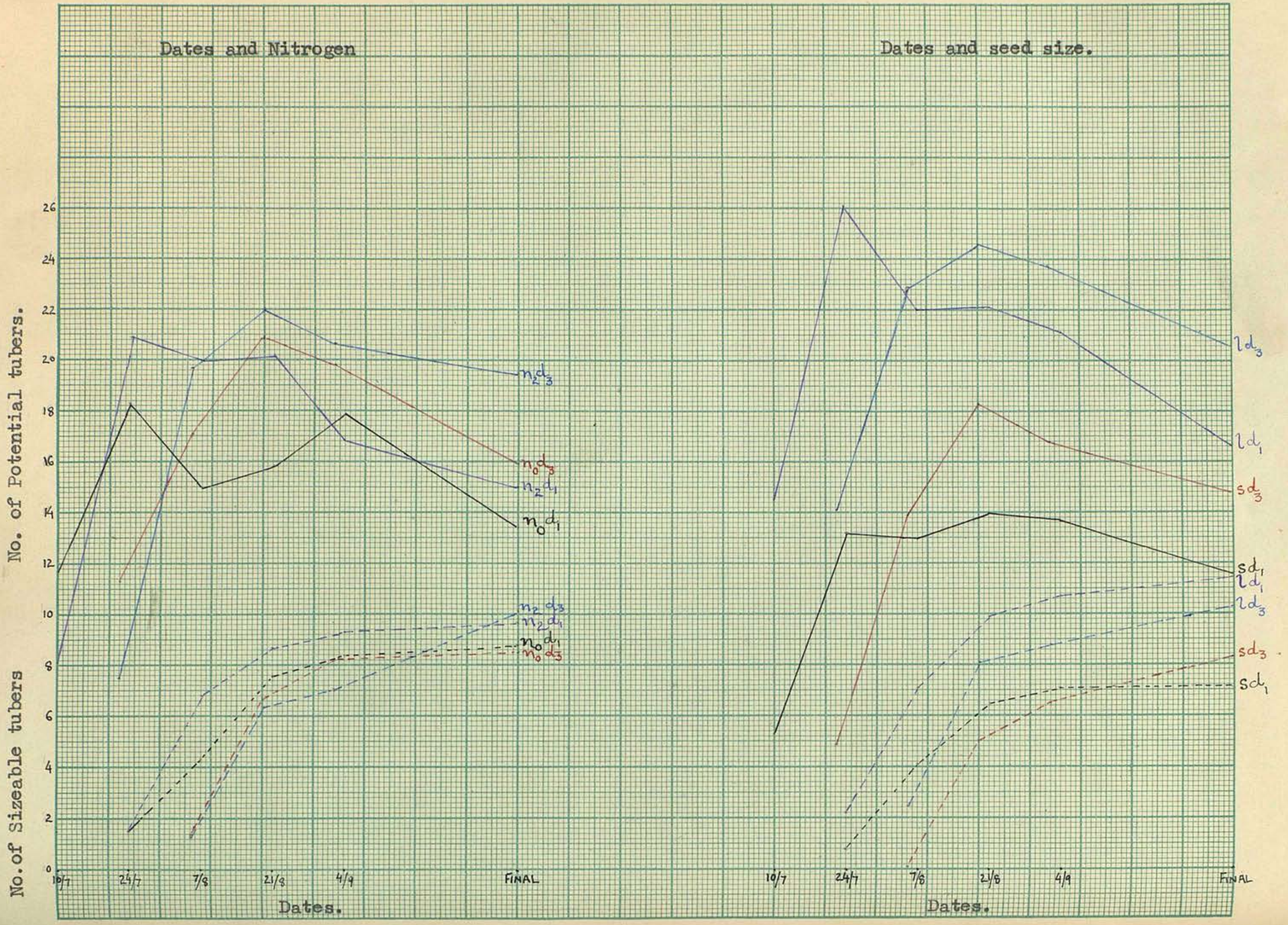
According to Russel (1937) 'Potassic fertilizers act well in cold sunless seasons'. If this is true it would appear that the high assimilation rates caused by the muriate of potash were due to the $C\bar{l}$ ion rather than the potash ion. Potash did not appear to be limiting in the experiment for there were no potash deficiency symptoms in the untreated plots. It is possible that on account of the succulence of leaves induced by the muriate, the leaves were able to function more effectively during the dry and bright weather. A further analysis of the data revealed that 'muriate' appeared to increase the assimilation in the early stages, but it did so solely in the presence of nitrogen (Table L11). Contrariwise, in the later stages the effect of the 'muriate' was obtained in the absence of nitrogen. Thus not only the interaction N x K was prominently depicted, but it was further conditioned by the 'time' factor. For this complex relation again, the hypothesis of the specific actions of the different ions, K and $C\bar{l}$, seems adequate. In the early stages, the effect was probably exercised by K under conditions tending to be crowded (i.e. in the presence of nitrogen) for K is a replacer of light. In the later stages, during the period of comparative dryness, $C\bar{l}$ ion pre-dominated in effect but the effect was well marked only in the absence of nitrogen. In the presence of N, the effect was not high as the interaction N x K on vegetative growth produced a thick mat and the plants virtually lodged under these/

these conditions. The inaccessibility of light and CO_2 under these conditions limited the assimilation rate.

The effects of seed size on the relative leaf growth rate, leaf-weight ratio and net assimilation rate were simple and clear-cut. A decrease in seed size raised the leaf-weight ratio as well as the net assimilation rate consistently during growth and irrespective of the planting time, and therefore an intensified effect appeared in the same direction on the efficiency index. The two counterbalancing tendencies tended to improve the status of the small seed and bring it in level with the plant with an initial advantage. The improvement in assimilation with small seed was evidently due to less shading or crowding and to better resources of light and nutrients available per unit leaf surface.

A delay in planting encouraged higher leaf-weight ratio. As late planting had a tendency to produce thinner leaves, the ratios on an area basis will be definitely in favour of late planting. The assimilation rates were also higher in the late planting during the period when maximum rates of assimilation occurred. The efficiency index of the late crop was therefore higher than the early planting. In the former the rate was exponential over a considerable length of time, while in the latter the rate fell off much earlier.

Fig 18 TREATMENT EFFECTS ON THE POTENTIAL AND THE SIZEABLE TUBERS.



The number of tubers: The effect of nitrogen and of seed size on the potential crop of new tubers (i.e. all tubers) as well as the sizeable crop (tubers over $1\frac{1}{4}$") can be studied from Fig. 18. The potash effect is summarised in Table LIII.

The potential crop of new tubers rapidly rose to a maximum within a relatively limited period and thereafter fell off steadily. Thus some of the new tuber initials laid down, never developed and were as a matter of fact "sucked back" both in the early and the late planting. The curves for sizeable tubers even, flattened out sooner than expected, on account of the drought conditions.

There was a distinct delay in the onset of tuberization through nitrogen application. The initial delay was, however, rapidly made up so that, almost at all stages, the stimulating effect of nitrogen on the laying down of new tubers was recorded. This was not brought about through any corresponding increase in the number of sprouts but was merely the result of increased meristematic activity which is a function of nitrogen.

Nitrogen also tended to nourish a greater number of the potential crop to sizeable tubers. This effect tended to show itself in early August in the first planting but came on very slowly in the late planting. The effect of N on the number of tubers did not reach a significant level due to drought. apparently.

The/

Table LIII. The effect of potash on the number of tubers.

		Early planting						Late planting				
		10/7	24/7	7/8	21/8	4/9	Final	22/7	5/8	19/8	2/9	Final
Potential	k_0	9.6	18.1	16.6	17.0	16.5	13.1	9.3	19.1	22.5	20.2	16.9
	k_1	10.2	21.1	18.5	19.1	18.3	15.3	9.6	17.6	20.4	20.3	18.4
Sizeable	k_0	-	1.5	5.2	7.5	8.2	8.5	-	1.4	5.5	7.0	9.0
	k_1	-	1.5	6.0	8.8	9.6	10.0	-	1.2	7.6	8.3	9.6

Table LIV A. Development of tuber size. Fresh weight per tuber (gm)

	10/7	24/7	7/8	21/8	4/9	Final	22/7	5/8	19/8	2/9	Final
n_0	1.9	8.2	17.8	27.4	29.2	44.3	1.3	6.3	17.8	24.2	37.4
n_2	1.6	7.1	18.2	29.9	40.5	61.4	1.3	5.9	18.6	23.8	42.5
k_0	1.8	7.8	17.2	26.4	34.0	54.0	1.4	6.3	15.5	22.5	41.3
k_1	1.7	7.5	18.8	30.9	35.8	51.8	1.2	5.9	20.9	25.5	38.7
s	1.1	7.2	18.5	29.9	38.8	58.2	.8	4.5	17.8	23.7	43.4
l	2.4	8.1	17.5	27.4	31.0	47.6	1.7	7.7	18.5	24.2	36.6

Table LIV B. Treatment effects on tuber size (chats excluded)

Dates and Nitrogen						Dates and seed size					
2-5/9			Final			2-5/9			Final		
	d_1	d_3		d_1	d_3		d_1	d_3		d_1	d_3
n_0	55.1	48.3	n_0	64.2	62.5	s	69.0	52.9	s	90.2	71.2
n_2	69.1	58.2	n_2	91.3	74.3	l	55.1	53.5	l	65.3	65.6

The effect of potash was similar to that of N and it was not statistically borne out.

The large seed laid down thrice as many tuber initials as were set by the small seed. The relative differences declined with time due most probably to internal competition in case of the large seed but the balance still remained in the favour of the large seed, which also carried a greater number of tubers to marketable size. The relation between the number of tubers and seed size was positive and it was not materially altered by a change in the level of other factors.

The laying down of the potential crop received no check under delayed planting. In fact it tended to be higher in the late planting than in the early. This may be due to a greater number of sprouts established by late planting. The sizeable tubers, however, lagged behind but eventually got very close to those of the early planting.

<u>Size of tubers</u>: Nitrogen introduced variations in the size of the tubers beyond the range of experimental errors (Table LIV). The size of tubers rose by about 40% through nitrogen manuring of the early planting. The magnitude of increase was smaller in the later planting. The D.N. interaction, which was recorded on the vegetative growth, also appeared in time, on the storage phase.

The effect of potash on the size of the individual tuber could not be significantly demonstrated, though it did raise the proportion of ware/

ware-sized potatoes in the produce (see later).

The size of seed at planting, slowly and gradually, influenced the size of tubers in the resulting crop, the relation being inverse, as in the 1946 experiment.

Deferred planting did not develop the size of tubers to the extent early planting did. The disadvantage of age was therefore not offset in the final crop. The decrease in size by late planting was, however, small in the absence of nitrogen or with the use of large seed. D.N. and D.Ss. were significant interaction on tuber size. D.Ss. interaction pointed in the reverse direction on tuber number and therefore cancelled out in yield.

TREATMENT EFFECTS ON FINAL YIELD.

Gross Yield of Tubers:

Treatment effects on the yield of tubers referred to earlier were based on the sampling data from the observation plots. The Yield results were studied on a wider basis from the individual plot records in the $3^4 \times 2$ main experiment. The analysis of variance (Table LV) reveals that the response to the time of planting was strictly linear and the deviation from the linear trend was of the order of random errors. Contrary to 1946 results, neither the linear nor the quadratic component of seed size or spacing effect approached significance. The effect of nitrogen was indisputable. A strong linear response to nitrogen was conditioned by a significant curvature of response. The effect of nitrogen was modified by planting date, spacing, and seed size as evidenced from the significant $\dot{D}.\dot{N}$, $\dot{N}.\ddot{S}p.$, and $\dot{N}.\dot{S}s.$ interactions. The effect of potash was demonstrable beyond doubt and it interacted strongly with nitrogen.

Summary tables for reference and in support of the above remarks are given (Tables LVI, LVII). The more important results are restated in general terms.

Nitrogen was the most potent factor. A single dressing of $2\frac{1}{2}$ cwt. per acre of sulphate of ammonia (20.6% N) raised the yield by about 33% over the basal yield. The higher dressing was a luxury dose for the extra dose was much less effective per unit of nitrogen. The falling off in the effectiveness of/

Table LV. Analysis of Variance. Final yield (main Experiment 1947) (sub-plot basis)

Due to	d.f.	Mean square	Due to	d.f.	Mean square	Due to	d.f.	Mean square
Blocks	2	9492	N'	1	488840^{xx}	K	1	83277^{xx}
D'	1	73581^{xx}	N''	1	57493^{xx}	N.K.	2	7225^{xx}
Ss'	1	7600	D'.N'	1	6962^{x}	D.K.	2	1363
Sp'	1	77	Sp'.N'	1	539	Sp.K.	2	475
D''	1	16	Ss'.N'	1	7729^{x}	Ss.K.	2	380
Ss''	1	8983	D'.N''	1	2716	Remainder error (c)	72	1423
Sp''	1	15805	D''.N'	1	6	Sub plots	161	
D'.Ss'	1	242	Sp'.N''	1	296			
D'.Sp'	1	27612	Sp''.N'	1	5985^{x}			
Sp'.Ss'	1	1467	Ss'.N''	1	1014			
Remainder = error (a)	15	8141	Ss''.N'	1	54			
			D''.N''	1	11			
Main plots	26		Sp''.N''	1	1823			
Sub-blocks (within blocks)	6	21065	Ss''.N''	1	4428			
			Remainder = error (b)	34	1466			
			plots	80				

Table LVI. Main effects of treatments on the gross yield of potatoes.

Tons per acre

Nitrogen		Potash		Planting date		Spacing		Seed size	
n_0	8.32	k_0	9.89	d_1	11.21	8"	10.71	s	10.13
n_1	11.22	k_1	11.11	d_2	10.49	12"	10.12	m	10.78
n_2	11.96			d_3	9.80	16"	10.67	l	10.58
linear	3.63^{xx} ± 0.199		1.22^{xx} ± 0.160		-1.41^{xx} ± .469		-0.05 ± .469		.45 ± .469
Quadratic:	-2.16^{xx} ± .344				.030 ± .812		1.14 ± .812		-.85 ± .812

of the extra dressing was steeper than would normally be expected according to the law of diminishing returns (Mitscherlich), due undoubtedly to the limiting influence of the 'water' factor in the year under report.

Potash had a much smaller effect than that of nitrogen, although it was highly significant. It was measured with the greatest precision by virtue of the nature of the design. The effect of potash was enhanced progressively as the level of nitrogen rose. The interdependence of the two factors was well brought out. It may be recalled that muriate of potash led to an increase in the water content of the tubers. A correction made for this factor would leave little balance in favour of the potassic fertilizer, in the absence of nitrogen. A substantial surplus would, however, still be left over in favour of potash, under conditions of heavy N-manuring. A satisfactory explanation of the potash effect involves a number of considerations: (1) The field was heavily dunged so that the potash status of the soil was not low. (2) The K^+ ion was introduced with the Cl^- ion, which is considered to be harmful to the potato among some other crops. (3) The harmful effect of Cl^- could not be general, for its indirect effects (through enhanced leaf succulence) or its interaction with nitrogen (e.g. by inducing greater utilization of nitrogen in growth) might influence the results differently.

It/

Table LVII. Interaction of factors on yield (tons per acre)

Nitrogen and Potash

	n_0	n_1	n_2
k_0	7.95	10.73	11.00
k	8.70	11.71	12.93
diff	0.75^{xx}	0.98^{xx}	1.93^{xx}
(.277)			

Dates and Potash.

	d_1	d_2	d_3
k_0	10.62	9.72	9.31
k	11.80	11.25	10.29
diff.	1.18^{xx}	1.53^{xx}	0.98^{xx}

Nitrogen and seed size

	s	m	l
n_0	7.53	8.78	8.66
n_1	11.11	11.22	11.33
n_2	11.75	12.36	11.76
n_2-n_0	4.22^{xx}	3.58^{xx}	3.10^{xx}
n_1-n_0	3.58^{xx}	2.44^{xx}	2.67^{xx}
n_2-n_1	0.64	1.14^{xx}	.43

Dates and Nitrogen

	d_1	d_2	d_3	
n_0	8.67	8.33	7.98	
n_1	12.13	11.19	10.34	
n_2	12.84	11.94	11.09	
n_2-n_0	4.17^{xx}	3.61^{xx}	3.11^{xx}	$\pm .344$
n_1-n_0	3.46^{xx}	2.86^{xx}	2.36^{xx}	
n_2-n_1	0.71^{x}	$.75^{x}$	$.75^{x}$	

Nitrogen and spacing

	n_0	n_1	n_2	n_2-n_0	n_1-n_0	n_2-n_1
8"	8.68	11.28	12.18	3.50	2.60	.90
12"	7.57	11.02	11.77	4.20	3.45	.75
16"	8.72	11.36	11.92	3.20	2.64	.56

It appears that in the absence of nitrogen, any improvement due to K^{+} or Cl^{-} in the later stages was largely counter-balanced by an earlier adverse effect of Cl^{-}. In the presence of nitrogen, the early injurious effect of Cl^{-} was entirely masked by its indirect effects as above or by the interaction of NO_3 and K, resulting in the utilization of absorbed nutrients for growth. The early interaction on growth had an enduring effect on the ultimate plant performance, in a dry year.

A delay in planting by a fortnight amounted to a loss of 0.7 ton potatoes per acre. This is equivalent to a loss of 1 cwt. per acre per day of delay. The loss was greater in 1946 which was characterised by a wet summer. The relative potency of this factor becomes at once clear, when it is realized that it involves no monetary expenditure in contradistinction to nitrogen.

The behaviour of planting time was influenced by nitrogen and vice versa. The three plantings did not materially differ in the absence of nitrogenous dressings. The superiority of the early plantings became patent as the level of fertility rose. In other words, the response to nitrogen declined as planting was done successively later. This appears to be a truth of general applicability, for it is obtained in other plants growing under widely different conditions of soil and climate (Gregory et al, 1932, Dastur and Singh, 1944). The effectiveness of the extra dose of N,/

N, over and above the single dressing, was not further enhanced by early planting even, due to drought.

Potash showed no differential behaviour with planting time and vice versa. The bright sunny and dry summer was no test for the evaluation of the postulated relation of potash with planting date. Besides, the trial of 'muriate' to the exclusion of potassium sulphate and a basal application of dung rendered abortive an attempt to explore this relation.

The potentialities of increase in seed size and in plant population by spacing, did not bring their promised returns in yield. This is explained later.

It is interesting to note that the response to nitrogen declined with increase in seed size. The small seed gave the maximum response. This result seems to be conditioned by the seasonal factor. The acuter competition for water with increasing seed size, limited its fertilizer response in the dry year. In a wet summer, the better ramification of roots and the greater potential crop produced by large seed should lead to a greater fertilizer response.

12" spacing was conducive to higher response to nitrogen than the close and the wide spacing. It seems that if water were not a limiting factor even closer spacing might have been optimal for response to nitrogen, but as the close spacing rendered the plants vulnerable to the rigours of drought, it was revealed to be less efficient in the use of nitrogen.

<u>Soil texture and the fertilizer response:</u> The sub-blocks/

sub-blocks varied considerably in the physical character of the soil and the crop yields. However, the response to nitrogen or potash showed no simple relationships with the variations in the soil texture. Heavy soil was as responsive, if not more, as the light soil. This lends confirmatory support to the finding of Russel and Garner (1941).

The response to nitrogen in the different blocks seemed to be inversely related to their basal yields, in conformity with the law of diminishing returns, which was also brought out by the falling off in the effectiveness of the extra dressing over the single dose.

Grades of produce:

The contributions of the different grades to the aggregate yield under different sets of conditions can be seen from Table LVIII.

Nitrogen: The absolute increase in the total yield through nitrogen was made up partly of 'ware' and partly of 'seed' but largely of the former grade. Chats contributed little to the yield increase. The percentage distributions of the grades of yield revealed conclusively the influence of N in raising the ware in proportion to the chats and the seeds. The effect of nitrogen on the size of tubers, recorded earlier, pointed in the same direction. Thus nitrogen operated through its influence on the size rather than the number of tubers, although the general belief is to the contrary (Russel and Garner, 1941). The fact is that/

Table LVIII. The absolute and the relative contributions of the different grades to the aggregate yield

	Tons per acre			Percentages		
	Ware	Seed	Chats	Ware	Seed	Chats
Nitrogen						
n_0	1.78	6.11	0.43	21.4	73.4	5.2
n_1	3.40	7.43	0.39	30.3	66.2	3.5
n_2	4.62	7.01	0.33	38.6	58.6	2.7
Potash						
k_0	2.78	6.76	.35	28.1	68.4	3.5
k_1	3.57	7.09	.45	32.2	63.8	4.0
Planting dates.						
d_1	3.33	7.51	.37	29.7	67.0	3.3
d_2	3.13	6.95	.41	29.8	66.3	3.9
d_3	3.02	6.38	.39	30.9	65.1	3.9
Spacing						
8"	2.37	7.81	.54	22.1	72.9	5.0
12"	2.98	6.76	.38	29.4	66.8	3.8
16"	4.14	6.25	.27	38.8	58.6	2.6
Seed size						
s	3.83	6.05	.25	37.8	59.7	2.5
m	3.18	7.19	.40	29.5	66.7	3.8
l	2.44	7.60	.54	23.0	71.8	5.2

Table LIX. The effect of seed size and spacing on the gross and the net yields.

Tons per acre

	Gross yield			Seed used			Net yield (i.e. Gross - seed used)			
	8"	12"	16"	8"	12"	16"	8"	12"	16"	mean
s	10.40	9.59	10.41	.81	.54	.40	9.59	9.05	10.01	9.55
m	10.59	10.84	10.93	1.62	1.08	.81	8.97	9.76	10.12	9.61
l	11.15	9.94	10.67	3.24	2.16	1.62	7.91	7.78	9.05	8.25
mean							8.82	8.86	9.73	

that the plant treated with nitrogen did induce more tubers to set but only a fraction of them developed into sizeable crop. Some of them were even sucked back under strain of water shortage. The practical usefulness of the excess consisted solely in the assurance they afforded in case something happened to those developing ahead of them or in their capacity to store the surplus food left over after the 'senior' had developed to the full size. The internal competition for water only enabled a fraction of the tubers to develop and those which were left behind did not get a chance to make their contribution, for the favourable weather never returned.

Potash: Potash influenced all the grades to a greater or a lesser degree but its effect was most marked on the 'ware'. The percentage ware was distinctly higher in the presence of potash than in its absence.

Planting date: The superiority of early planting was contributed both by 'seed' and 'ware' grades but not by thirds. The percentage distribution of the crop in grades was not influenced by this factor in the year under review. The ware proportion was distinctly raised in the preceding year by early planting and is to be expected in the case of a 'time' factor. This clearly indicates that in 1947 the early planting suffered more from the drought than the late planting. Thus an early planting would profit more from nitrogen(as shown earlier) as well as/

as water. This also explains why the fall in yield with delay in planting was linear in 1947, but became steeper in 1946 with progressive delay in planting.

A wet season in case of late planting upsets the balance between the storage phase and the vegetative phase but in case of early planting it leads to a development in the size of tubers to a greater extent relatively. Thus the gap between the planting dates in regard to yield widens in a wet summer. The intensity of weather changes and the stage of crop at the time of their onset are, however, important modifying factors. For example, if a planting has been early enough to complete the storage phase, largely, before a wet or dry weather breaks, it would be insensitive to such changes in the weather conditions, which may influence the later plantings one way or the other.

<u>Seed size and spacing:</u> Whereas the aggregate yields were not influenced by any of the two factors, the absolute amounts of the different grades were greatly influenced by each of them. The same remarks apply to the percentage distribution of the crop in grades.

The seed fraction as well as the chats increased progressively with increase in seed size or the plant population. The converse held true of the 'ware'. The magnitude of effects on the two main grades were of the same order but the direction was opposite so that the yields were equalized over a wide range of spacing or seed size. The full potentialities of the/

the large seed or the close spacing did not find expression,on account of the limiting influence of some factor. That these potentialities did exist as much in 1947 as in the preceding year is indisputable,for smaller fractions were directly related to the seed size and plant density. If a fraction of the undeveloped crop could have enlarged to full size, as it did in 1946 when chats made no contribution to yield, it would have made all the difference. The plants from large seed as well as close spacing,with their greater number of tubers, all set within a relatively short time, had too many mouths to feed. This constituted a potential advantage which required all other factors at non-limiting levels. As water supply was stringent in 1947, the scales turned over and the expected gain did not materialise.

In 1946, although the directions of effects on the yields of the grades were much the same as in 1947, the essential difference was that the increase in seed fraction from increasing seed sizes or plant densities more than outweighed the depression in ware. In 1947, the increase in seed was at the expense of ware and the yields just balanced up. Thus the same amount of storage material was distributed over a greater number of tubers in case of large seed or close spacing. It is not surprising that the plants from small seed (or wide spacing) adequately compensated for the initial disadvantage, for they had/

had higher leaf-weight ratios as well as higher net assimilation rate, as already explained. But it may be noted that they never out-yielded the plants raised from large seed or close spacing. Close spacing was more efficient than the large seed, for seed production. Halving the spacing produced the same effect as quadrupling the seed size.

Net Yield: The complete failure of seed size and spacing factors on the gross yields in 1947, suggested that the extra investment in the form of seed requirements entailed by close spacing and the use of large seed was a net loss. In the preceding year, they had given extra yields, at least equivalent to the extra seed put in, and by altering the relative proportions of the grades in the net yield their value lay in their use in the seed-producing districts.

The seed requirements under the different combinations of seed sizes and spacings in this experiment, ranged from 0.4 ton to 3.24 ton per acre (Table LIX). The extra yield under these conditions (Gross yield-seed used) revealed convincingly the risk involved in the use of seed larger than 2 oz. and the spacing closer than 16". The risk is not, however, uniformly distributed. The great need is to balance seed size and spacing - a point which this experiment sought to elucidate. The minimum net crop (about 8 tons per acre) was obtained with large seed closely spaced. These were the conditions of maximum possible sprout density which is a measure of competition. The maximum/

Table LX. The analysis of net yield into grades.

	Ware			Net seed			Chats		
	8"	12"	16"	8"	12"	16"	8"	12"	16"
s	3.07	3.38	5.05	6.19	5.42	4.78	.34	.24	.17
m	1.95	3.57	4.07	6.44	5.83	5.78	.57	.37	.27
l	2.04	2.00	3.27	5.15	5.24	5.39	.72	.54	.38

Table LXI. The performance of cut seed.

Yield of tubers (tons per acre)

		1 oz.	2 oz.	4 oz.	mean ±.272
	Whole	9.01	9.49	8.45	8.98
Cut	Lengthwise	8.72	8.72	10.17	9.20
Cut	Heel	8.72	9.43	9.90	9.35
Cut	Rose	7.48	8.97	9.70	8.71
	mean ±.459	8.48	9.15	9.55	

maximum yield (about 10 tons p.a.) was registered under conditions of least competition. The rest of the yields deviated about a mean yield of about 9 tons per acre. Despite the wide variations in the two seasons, the conclusion from a practical point of view is not modified greatly.

The matter can be followed up to study the composition of the yield in grades to judge the relative value of the different treatment combinations and to get a clue to their success or failure (Table LX). In the case of the crop raised from small seed, the produce of net seed (gross-seed - seed used at planting) still increased as the spacing narrowed. The increases largely covered up the corresponding depressions in the ware. Thus even in a dry year the small seed could be spaced close, in a seed producing area. The spacing effect of the above type on net yield of seed gradually vanished as the seed size at planting was raised from small to large, but it appeared in an intensified form on the chat fraction. This re-emphasises the acute competition which prevented the development of considerable quantities of small chats to sizeable tubers under conditions where large seed combined with close spacing. The risk involved in the use of such combinations becomes still more glaring in that, apart from the low net yields, they are composed of relatively more of valueless material.

To get a precise picture of the relative position of the/

the different treatment combinations, the various grades should be weighted in accordance with the price levels of the different grades. The price is however variable. Taking the two years' results together and assuming that they represent the maximum divergence within which the performance of seed size and spacing may vary (one being an exceptionally wet and the other being an extraordinarily dry year) it can be tentatively put forward that the following scheme should hold over a number of years, in seed-producing areas:-

Small seed	8" spacing
medium seed	12" "
Large seed	16" "

<u>Cutting of seed</u>: The performance of cut seed in comparison to the whole seed of equivalent size was tested in a preliminary experiment where the mainplots, in duplicate, included the levels of quantity (1 oz., 2 oz., and 4 oz., seed weights per 3 sq. ft. area) and the subplots, the qualitative comparisons (whole, cut lengthwise, heel-end and the rose-end). Successively double-sized seeds were halved, as required, to plant at the normal spacing beside the 1 oz. and the 2 oz. whole seed respectively. In case of the mainplots designated to be planted with 4 oz. seed material, per 3 sq. ft. area, the 4 oz whole tubers planted at the normal distance of 16" were compared with the halved ones spaced at half the distance. Cutting was done on/

on 3 May and the planting on 8 May. The subplot comprised a single drill 20' long. Borders were provided only between the mainplots (levels of quantity). The plots were uniformly manured at 5 cwt. per acre complete potato fertilizer.

On the average, the cut seed compared well with the whole seed of the same size (Table LXI) and the manner of cutting was of little consequence. The heel end was as good as the rose end. Indications were that small and medium seed should preferably be used whole. This is in support of the results of Stewart (1922). On the contrary, large seed could be profitably halved and spaced close, at least in seed-producing districts. In ware-producing areas, economy in seed could be affected by the use of cut seed at normal or wide spacing. The success with cut seed, however, depends on other factors (Priestley and Johnson, 1925; Bell et al (1942)

Before discussing the results of the two years' experiments, it would be of interest to examine the usefulness of the designs of the main experiments which were split-plot designs incorporating the 'confounding' of the high-order interactions.

<u>The efficiency of designs (1946 and 1947):-</u>

A reference to the analysis of variance tables for yield (p.50,112) reveals that the transverse subblocks created by confounding removed considerable variation in either of the two years, particularly so in 1947. The gain in efficiency through confounding can be computed by Yates' method (1937). In 1946, the error (b) mean square would have risen from 2002 to 3052,

in/

in the absence of confounding, (Table LXII). Similarly, in the absence of an array-strip arrangement for lifting time, the error (d) mean square would have risen from 1050 to 1586. The gain in efficiency is of the order of 50% in either case. Thus the three errors would have been in the ratio of 1:2:4 in a straight-forward successive plot division, unconfounded and without array strip arrangement. The transverse restrictions altered the ratio to 1:1.91:5.91, approximating closely to the corresponding subplots in the semi-mainplots and the mainplots i.e. 1:2:6. Similarly, the ratio of the variance for the lifting time strips to the sub-blocks is 1:1.9 corresponding to the expected 1:2. In other words, the standard errors <u>per plot</u> were maintained over a considerable range of plot sizes. The efficiency of a small plot can be improved by a proper 'local control', although normally standard errors per plot increase as the plot size is reduced below $\frac{1}{20}$ - $\frac{1}{40}$ acre.

The errors per plot were unusually low in 1946. A plot as small as $\frac{1}{220}$ gave less than 6% S.E. per plot. In the succeeding season, the experimental site was more variable comparatively, although the errors were of the order encountered in well conducted experiments (Garner and Weil, 1939). The gain through confounding was particularly high in 1947. The ratios of variances of the successively larger plots to that for the sub-plot (Sub-plot basis of analysis) would have been 1:2.56: 5.72 in case no confounding were/

Table LXII. The effect of transverse restrictions (through confounding and array strip arrangement) on the error estimates.

	m/sq. (Sub-plot basis)		Error ratios		Plot sizes		S.E. per plot (direct basis)		
1946	(1) As designed	(2) No transverse restrictions	r_1	r_2	feet	acre	(1) As designed tons p.a.	% mean	(2) No transverse restrictions % mean
(a) Error main plot	6276	6276	5.97(6)	3.95	9x132	1/36.6	.794	5.75	5.75
(b) " semi " "	2002	3052	1.91(2)	1.92	9x44	1/110	.777	5.63	6.94
(d) " sub-plot	1050	1586	1	1	9x22	1/220	.796	5.76	7.08
(c) " arrays	5876		1		81x22	1/24.4	.621	4.49	
Subblocks	11450		1.95(2)						
1947									
(a) Error main plot	8141	8141	5.72(6)	5.72	9x120	1/40.3	.995	9.48	9.48
(b) " semi " "	1466	3644	1.03(2)	2.56	9x40	1/121	.731	6.96	11.0
(c) " sub plots	1423	1423	1	1	9x20	1/242	1.019	9.70	9.70

r_1 = ratios 'as designed' with number of sub divisions across in parentheses.

r_2 = ratios if no transverse restrictions existed, with the number of sub divisions across in parentheses.

were adopted. With confounding, the error (b) was reduced to as low as the sub-plot error (c). Thus the ratio between $\frac{\text{error a}}{\text{error b}} = 5.7$ while the corresponding semi-main plots per main plot were 3. The sub-plot error (c) would have also gone down if a transverse restriction could be imposed.

Whenever the sub-plots lie end on in the main plots, and not side by side, the introduction of confounding is promising. The main plots should be compensated by taking account of fertility gradient, the provision of long narrow plots and if possible by covariance (Wishart and Sanders, 1935). The comparison of error mean squares with sub-block errors indicates that in either of the two years the direction of the run of the mainplots within blocks (N - S) was sound. The variability North - South was smaller in magnitude than that East - West.

It is instructive to compute what the mean squares would have been if instead of split-plot arrengement a partial or complete randomisation of the treatment combinations was adopted within the main-blocks. This is shown in Table LXIII which is self- explanatory.

Table LXIII. Estimate of error if split plot arrangement were replaced partially or wholly by unrestricted randomisation (calculated from column No.2 Table LXII - no transverse restrictions).

	1946 Usual splits.	1946 Absence of split plot Partial	1946 Absence of split plot Complete		1947 Usual splits.	1947 Absence of split plot Partial	1947 Absence of split plot Complete
Error (a)	6276	4044	2792	(a)	8141	5028	3191
Error (b)	3052	2173		(b)	3644	2312	
Error (d)	1586			(c)	1423		

If confounding existed as designed but the first splitting were omitted (i.e. smaller plots could be used for main plot treatments) error (a) and (b) would have merged to give m/sq. as 3427 and 3691 in 1946 and 1947 respectively.

DISCUSSION.

Regardless of the habitat of the plant, the total growth which is the 'finished product of the metabolic loom', is a function of the initial weight, the relative rate of increase in dry matter and time. Mathematically, $W_1 = W_0 \cdot e^{rt}$ according to the compound-interest law of growth (Blackman, 1919). It would therefore be normally expected that the seed size factor would induce variations in plant growth directly by virtue of the differences in the initial food store which represents the working capital with which the plant makes a start. As growth is exponential a small initial gain may multiply manifold within a relatively short time to produce a large and lasting effect on the future development. A shift in the date of planting or of lifting would naturally involve the time factor or the length of season and thereby the ultimate plant performance. Other factors such as spacing, nutrient supply, water etc., may be supposed to operate through a modification in the rate of increase, per unit of material per unit of time. The three main components of growth are not strictly independent. Any factor calculated to influence one of them favourably might occasion an adverse effect on one or both of the other components. Conversely, a plant handicapped in one respect might evoke a new response to the new circumstance and might so modify its internal economy as to produce an extraordinary result. The observed effects may therefore/

therefore deviate from the expected ones in direction or magnitude to a varying degree. The present investigation involved a study in the potato of the factors calculated to affect the three different components, individually and in combination, and it would be interesting to study the plant reaction to the different conditions and to follow, in the right sequence, the course of events leading up to the final yield. It is thus possible to study the influence on the total growth on the one hand, and the phases of growth on the other, and establish the relationships between growth and the yield, which at any rate is the aim of an agricultural investigation. A knowledge of such relationships would go a long way in suggesting the trends in the modification of the cultural practices and, clearly, combines interest with usefulness.

A study of the growth behaviour under different seed sizes in the potato unmistakably reveals that early growth is proportional to the size of seed. That this is not surprising is seen from the fact that the concentration of total sugars are not materially influenced by this factor, so that the absolute sugar contents are more or less proportional to seed size. In other words, not only the total 'reserves' but the 'working capital' is more and more as the seed size enlarges, and begins to be utilized as soon as the rest period is over and external conditions favourable for growth are prevalent. Other

'seed'/

'seed' factors are also not limiting in the large seed for it begins to chit earlier and rapidly and, in a rooting medium, sends out a more extensive adventitious root ramification which ensures a rapid supply of water (and nutrients) so that the sprouts make an earlier appearance above ground. The magnitude of differences in the time of sprout establishment from different seed sizes may vary but the direction is immutable. The resources of large seed, therefore, confer on the plant another potential advantage i.e. the "time factor".

It is natural to ask why the small seed which is bigger than the largest true seed of any other plant, makes such a slow early progress. Appleman (1918) surmised the possibility of a limited supply of growth promoting substances in the small seed. Direct evidence on the subject is lacking but it can be supported on theoretical grounds. The small seed represents that fraction of the previous year's crop, which did not develop to the full as a result of competition with the more favourably placed individuals. It appears the competition for substances which limited the extension of cells was antecedent to that for raw material. It may be suggested that small seed may be representing a late-set crop. But the differences in the age of the small and the large seed do not come into the picture, for all the tubers are set within a relatively short time, and also the position of the tuber initials on the sprout may modify the differences in/

in respect of age. An explanation on the basis of competition for growth-promoting substances should be adequate even if the small and the large tubers are not widely different in age. The differences in the number of sprouts per tuber, which is a measure of 'apical dominance', in the different seed sizes, again suggest the operation of a hormonal mechanism. The slow expansion of the first few internodes in the small seed, too, points in the same direction, for the cell enlargement phase is a function of auxins.

Although the sprout number is directly related to seed size, it is not proportional to the size of seed. This leaves the individual sprouts of large seed better nourished. They expand their leaves rapidly. It is interesting to note that a lot of food material is utilized from the mother tuber for the setting up of the photosynthetic apparatus, and the assimilating power of the young leaves is nil or very low for some time after emergence. The plants are virtually marking time, for any assimilation is balanced by respiration. This explains why amputation of the mother tuber in the early stages was critical in the experiments of Denny (1929).

High relative rates of depletion soon after emergence therefore occur all over, especially in case of the small tuber. Not all the food material is, however, used up for setting up the independent plant capable of carrying on its life processes through photosynthesis. A comparatively larger surplus is left over in case of the large seed and this/

this is apparently used in laying down the stolons and tuber initials for which the necessary points are already secured by the number of sprouts. The large seed thus ensure~~d~~s not only a larger but an earlier tuber set and prepares the way for the top growth to take over.

As soon as the role of the mother tuber is over, the tuberous primordia begin to compete with the other organs for elaborated foods. They start enlarging at the expense of other organs. As tubers constitute the non-assimilating part of the plant, the assimilating organs (the leaves) suffer and the relative rate of growth falls off. The greater the number of potential tubers and the earlier their onset, the larger and sooner the drain of material from the vegetative parts. Consequently, leaf weight ratio falls with increase in seed size and this gives the plants from small seed, a chance to improve their status.

There is yet another mode by which the plants from small seed tend to get level with those of the large seed. The net assimilation rate of the leaves is consistently higher in the former than in the latter case. This is explicable in terms of more light and mineral resources per unit leaf material.

The higher leaf-weight ratio ensured by small seed is brought about in more than one way. The leaves up the main axis expand. The number of leaves increase on the stem. An axillary development is induced more particularly/

particularly near the ground level where the internodes are short and a phenomenon akin to 'tillering' in cereals results. As a result of continued leaf activity, the maturity is delayed in the small seed. This tends to off-set in vegetative growth the disadvantage of delayed emergence.

The co-ordinated interplay of higher leaf weight ratios and higher assimilation rates, coupled with delayed maturity, improves the performance of small seed in total growth. In a wet year the vegetative growth may even exceed that of the large seed but in a dry year it may lag behind.

It is interesting that in the potato the relation between vegetative growth and storage is inverse, within limits, inasmuch as the small seed outgrows the large seed in a wet year, at the expense of storage, but in a dry year its lagging behind brings it to the level of large seed in tuber yields. In either case, a higher shoot/tuber ratio raises the size of the individual tuber of a crop from small seed.

The effect of spacing can be explained in the same manner as that of seed size. The essential differences are that (1) sprout population increases in proportion to the decrease of spacing (2) Spacing induces no differences in the time of emergence. Apart from these, the two factors are analogous in that both of them influence sprout density per unit area, so much so that when close spacing and large seed are employed simultaneously their returns are not commensurate with the extra seed costs/

costs, on account of the intense competition resulting from these conditions. This is also understandable according to the law of diminishing returns (mitscherlich). The competition may be aggravated in severity in a dry year.

A delay in planting by a given interval does not bring about an equivalent delay in emergence. Emergence follows in a quicker succession as planting is done successively later. Even then the diminished gap introduces important changes in growth behaviour and ultimate yield. The expansion phase of growth is stimulated in the late planting so that the internodes lengthen and the leaf size is larger. The plants rapidly make up in height and finally gain ascendancy over the early planting, by virtue of longer internodes. Leaf-weight ratio is higher and the rates of assimilation are not lower, for the plants are exposed to higher temperatures, in general, at corresponding stages of plant development during the vegetative phase. The efficiency index is ,therefore,higher and the plant makes up or exceeds in dry matter production in spite of age differences, in the absence of nitrogen. There is,however, a lack of balance between the vegetative and the storage phase in the late planting, so that the tuber yield declines slightly inspite of a large positive effect on the vegetative growth. The position of late planting goes from bad to worse under conditions of plentiful supply of nitrogen. It certainly is not inefficient in the removal and the utilization/

utilization of the fertilizer treatment, for the top growth makes up fully in a dry year and may even surpass the early planting under good supply of soil moisture. But the storage efficiency is lower and the length of season is inelastic inasmuch as the commensurate gain from vegetative development does not accrue to the tubers. The yield falls steeply as planting is done successively later, in the presence of nitrogen. The performance of late planting may further suffer in a year of late blight.

What stimulates the late crop to vegetative activity ?. On the strength of the influence on the internodal length, it is tempting to infer that a hormonal mechanism is involved. The role of auxins in the cell-enlargement phase is well established. The distribution of auxins is presumably controlled by two main factors which vary to a smaller extent from year to year, viz., the day length and the night temperatures. The potato plant exhibits an amazing reaction to the day length (Driver and Hawkes, 1943). It was observed in the course of this investigation that small seed planted late and well-manured had a tendency to develop long stolons, a behaviour akin to that observed for species, adapted to short day - length, when grown under long-day conditions. There was also a distinct evidence of more profuse flowering in the late planting. Apparently the partition ratio of metabolites was affected by the auxin distribution under the influence of external factors but it is difficult/

difficult to single out the critical factor controlling the response in development. The late-sown mangolds and sugar beet too have a similar tendency to grow vegetatively (Watson and Baptiste, 1938).

Nitrogen application irrespective of the planting time encourages vegetative growth to a proportionately greater extent and thus lowers the storage efficiency. Still it is the most potent factor for the yields of the potato. The increase in total growth and the yield of tubers is brought about through two sources (a) higher leaf weight ratio (b) an extension of 'time' factor. These two sources exercise an effect of a sufficient magnitude to offset any depression in the net assimilation rate caused by shading under conditions of high nitrogen supply.

The usefulness of nitrogen varies with a change of conditions. Mention has already been made to its relation with planting time. Early plantings are the most responsive to nitrogen. The interaction of nitrogen with the muriate of potash ~~in~~ is another outstanding feature of this investigation. Nitrogen depends for expression into growth upon this treatment. In the absence of nitrogen, the effect of potash is completely obscured, but it appears as the level of nitrogen rises. The mode of effect is by no means simple, particularly because the relative influences of K^+ and Cl^- cannot be isolated, so far as the present investigation goes, although a working explanation is offered in the section on growth analysis. The deleterious/

deleterious effect of the Cl^- ion on the potato has been indicated by previous investigations (Russel and Garner, 1941; Cowie, 1943). It is highly improbable that it interferes with sugar production for its value for sugar beet and mangold is proved beyond doubt. The Cl^- ion, however, leads to a greater succulence of leaves so that in a drought year it may exercise a beneficial effect on the potato to offset its injurious effect in other ways.

SUMMARY.

The investigation embodies the results of two comprehensive multi-factor experiments, coupled with observation plots, carried out at the Boghall Experimental Farm during the years 1946 and 1947 to study the optimal levels of the diverse factors and their optimal relations in the potato (var. Gladstone). Detailed periodic growth observations were taken on the selected treatments.

The sprouts from small seed emerged later, were fewer in number, had smaller reserves as well as the assimilable sugars per sprout, and had slower early development.

The percentage rate of depletion of food material from the mother tuber was not much affected by seed size. About 10-15% of the total food store was enough to bring the sprouts near ground level with good root ramification. Much higher demands on the mother tuber were made during expansion of leaf primordia, when the assimilation rate of the young leaves was surprisingly low or negative. Concurrently, the sugar content of the mother tubers increased.

More than 50% of the original dry matter was present in the old tubers after sprout establishment and this continued to be used by the sprouts apparently for laying down stolons and tuber initials till it fell down to 20-25%. A larger absolute surplus in the large seed made for an earlier and greater tuber set at points assured/

assured by more sprouts.

Fewer sprouts and tuber initials in case of small seed, usurped smaller proportion of the assimilates giving the plants a chance to recoup in vegetative vigour. The leaf-weight-ratio as well as net assimilation rate was consistently higher in the plants from small seed. Axillary development below and the expansion of leaves above constituted the compensatory mechanism in growth, in case of the small seed.

The size of new potatoes or the proportion of ware in the produce rose as the seed size decreased, due to higher $\frac{\text{shoot}}{\text{tuber number}}$ ratio.

In the wet year, the plants from small seed outgrew those from large seed but the compensation (through improvement in tuber size) was inadequate to offset in yield the depression through tuber number.

In the dry year, the potential crop set by large seed was not all carried into sizeable potatoes for want of water so that the small seed produced about as much yield as the large.

The effects of spacing on the early growth, later development, tuber size, tuber number and the gross yields in the dry and the wet year were analogous to those of seed size. A unit change in the level of spacing, however, produced larger effect on the crop characters than that of seed size.

Closer spacing then 16" was risky if adopted with large seed but was normally a profitable proposition/

proposition if used with the small, medium or the cut large seed in seed-producing areas.

A delay in planting caused a delay in emergence by $1/3$ - $1/2$ the interval between plantings, and raised the sprout number slightly.

Late plantings had longer internodes, higher leaf weight ratio, greater succulence and higher relative growth rate, so that they excelled finally the early planting in vegetative growth and flowering but were inferior in tuber yields in either of the two years.

The superiority of early planting was enhanced by close spacing, wet summer or nitrogen application.

Nitrogen stimulated all phases of plant activity, viz., meristematic activity, extension growth, differentiation, and storage. It increased leaf-weight ratio sufficiently to maintain higher relative growth rate despite lower net assimilation rate consequent upon shading.

Nitrogen did not influence sprout establishment, tended to increase the potential tuber set and raised the tuber size or the ware proportion.

Nitrogen was the most potent factor for yield despite a basal dressing of organic manure and the dry weather in 1947. The double dressing was much less effective per unit N, and proved a luxury dose.

The response to nitrogen declined with advancing planting date, increasing seed size or rising basal yield. It was not influenced by variation in soil texture/

texture (within limits) and was definitely enhanced by muriate of potash.

The muriate of potash did not influence meristematic activity, increased extension growth and the water content of the plants and the tubers. The effect on growth and yield was masked in the absence of nitrogen, but improved with successive increments of nitrogen.

The results are discussed agrophysiologically and the statistical aspects of the designs employed are disserted.

ACKNOWLEDGMENTS

The author wishes to express his indebtedness to Professor Stephen J. Watson, University of Edinburgh, for inspiring guidance and continued encouragement and for extending the necessary facilities for work. Grateful thanks are also due to Dr. J.E. Gordon, Director of Studies and to Dr. A.M. Smith for helpful advice. Mr. A.S.B. Wilson, Farm Manager deserves special mention for the farming facilities.

The Usher Institute Authorities kindly permitted the use of their calculating machine for statistical treatment of the data.

The Department of Education, Government of India is thanked for the grant of a research scholarship for studies abroad.

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